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Climatic change or analysts' artifice? — a study of grid-point upper-air data

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Summary

Comparisons have been made between monthly and annual mean grid-point geopotentials and thicknesses for 20°N to 90°N computed in the Meteorological Office and corresponding values published by the German Federal Republic, USSR and USA. It is demonstrated that the disagreements are large over the oceans and subtropics, and that they are subject to variations and trends which make estimates of hemispheric climatic change unreliable. As a partial remedy it is suggested that a complete and quality-controlled data set of station upper-air observations be created, possibly eliminating some of the heterogeneity over land. However, to resolve the problem over the oceans will require at least the formation of a grid-point data set using an agreed optimum interpolation scheme which must not change with time. Until then, anything smaller than a dramatic hemispheric warming or cooling could escape the notice of users of grid-point data sets.

1. Introduction

The recent upsurge of interest in climatic change and variability has resulted in a pressing need to pay very careful attention to the quality of the data used, and to their interpretation. This paper illustrates the serious difficulties encountered when using grid-point values derived from upper-air data for studies of climatic change in the northern hemisphere.

It has been customary to monitor the earth's climate using data on surface temperature, pressure and rainfall. Surface data have advantages over upper-air data in that they comprise a close network over most land masses, and provide continuity for up to 300 years in a few places. However, in the past 25 years the network density of upper-air stations over land has comfortably exceeded the spatial resolution of mid-latitude synoptic weather systems, and therefore should also be adequate for monitoring climate. Moreover, upper-air data have other advantages: they are relatively unaffected by natural micro-meteorological features such as frost hollows, and by man-made ones such as urban heat-islands.

However, upper-air data suffer from two serious shortcomings. Firstly, the instrumentation, being of recent invention, has been undergoing substantial development, and it is very difficult to distinguish climatic variations from changes of instrumental origin, though given the appropriate information on the instruments it may not be impossible. Secondly—and this applies also to surface data—there are vast gaps in the network over the oceans. Coverage here is limited to a few rawinsonde observations from islands and weather ships, some aircraft reports of variable quality in the upper troposphere, and radiance-based soundings from satellites. Errors in the last appear to be about double the errors in

radiosonde data, using an objective analysis as 'truth' (Atkins 1979). To counteract these problems it would seem wise to make optimum use of the data by determining grid-point values on the basis of subjective or objective analyses which have used all observations simultaneously, from both fixed and mobile stations, preferably weighted according to their estimated quality. These grid-point values will be more reliable if the dynamical relationships between winds and geopotential fields have been used to improve the analysis in areas of sparse or heterogeneous data, and if a reliable forecast field has been used as a 'first-guess' or 'background' field for the analysis. Further improvements can be attained by incorporating corrections for known systematic errors for given stations, and corrections based on time or space consistency.

A serious disadvantage of grid-point values is that, the original data being heterogeneous, it is difficult to assess the quality of the analysis. Also if there is a progressive change in the relative proportions of different types of data which systematically differ, then the grid-point values may show spurious climatic change. This can also occur if the schemes for analysis, or for forecasting from past conditions in data-sparse areas, are changed; or, in the case of subjective analysis, if one analyst is replaced by another.

Angell and Korshover (1978) chose to use upper-air data for fixed observing stations to monitor climatic change of global and hemispheric temperature, and chose stations as evenly spaced as possible. However, their upper-air data set, although probably among the best available for fixed points, still has gaps, mainly over the oceans, sufficient to allow the possibility that variations there could pass unnoticed. Dronia (1974) and Harley (1978) used upper-air grid-point values from different sources and obtained mutually compatible results despite the problems listed above. Their results were also qualitatively compatible with those of Angell and Korshover (1977), quoted in Harley's (1978) Table 2 comparing a variety of authors, even though Angell and Korshover used a deeper layer of the atmosphere. The omission of the Pacific by Dronia may have aided this consistency, though Harley found that omitting the Pacific did not drastically affect the results for the northern hemisphere.

In the following sections the adequacy of upper-air grid-point values for studies of climatic change is investigated by comparing monthly and annual mean geopotential and 'thickness' (i.e. difference of geopotential) fields published by different analysis centres. Only general conclusions can be drawn, because it is not always possible in cases of disagreement to determine which analysis is to be preferred, and because two or more compatible analyses may be based on the same erroneous data. However, the results provide a useful insight into the magnitude of the problems.

2. Data

(a) *General description*

Mean monthly analyses for 1000 mb–500 mb thickness and for 500 mb geopotential are available both from the (British) Meteorological Office and from the German Federal Republic's Grosswetterlagen (GWL), from the 1940s to date. The analyses published in the USSR *Northern Hemisphere Synoptic Bulletin* include 500 mb geopotential and not 1000 mb–500 mb thickness, so to conduct a mutual comparison, 500 mb geopotential had to be used. The only available source of published USA analyses is the National Meteorological Center 700 mb geopotentials in the *Monthly Weather Review*. These were compared with 700 mb geopotentials in the USSR *Northern Hemisphere Synoptic Bulletin*, and could thereby be compared indirectly with the other nations' analyses which do not include 700 mb geopotential.

The USA and USSR analyses are in the form of contour charts, as are the GWL ones from 1978 onwards. Grid-point values were extracted manually from these, at 10° longitude intervals at 20°, 30°,

40°, 50° and 60°N, at 20° longitude intervals at 70°N, at 60° longitude intervals at 80°N, and at the North Pole. The UK analyses, and the earlier GWL ones, are already in grid-point form.

Because of the interest in current climatic change, and the pressing need to detect, for example, any warming due to increases in carbon dioxide, the aim was to compare analyses for the most recent 5-year period. However, because analyses for 1978 from the USSR were not yet all available, the period 1973–77 was selected for detailed study of monthly analyses, and of annual analyses derived from them. Some comparisons of UK and GWL 500 mb geopotentials and 1000 mb–500 mb thicknesses for 1978 and 1979 are included in order to illustrate the current situation. Also, to provide a longer historical perspective, annual mean 500 mb geopotentials at grid points for 1964–72 available in the GWL were compared with corresponding UK values.

Climatic change is more often monitored in terms of temperature or thickness than absolute geopotential. It will be assumed in this work that differences in 500 mb geopotential analysis can be regarded as approximately equal differences in 1000 mb–500 mb thickness analysis, i.e. that the surface pressure or 1000 mb geopotential analyses agree, which is plausible because the surface data are more plentiful. Trends in differences between 500 mb geopotential analysis can then be regarded as trends in differences between thickness analyses, i.e. as spurious relative warmings or coolings of the atmosphere. The reliability of this assumption has been tested by comparing a chart of thickness differences (Figure 1(e)) with a chart of 500 mb geopotential differences (Figure 1(c)). Clearly the assumption is not unreasonable but neither is it always precise. However, because 1000 mb–500 mb thickness data are not published by two of the four centres whose analyses have been studied, the use of 500 mb geopotential has been regarded as a justifiable substitute.

(b) *Details of sources of grid-point values*

(i) *United Kingdom.* The UK grid-point values are based on daily 00 GMT analyses. Since 21 August 1975 a forecast made from the analysis 12 hours earlier has been used as a starting point or 'background field' for each 00 GMT analysis and will therefore have had considerable influence in data-sparse regions. In addition, operational subjective intervention has been used to ensure consistency with other levels of the atmosphere (particularly 300 mb where aircraft reports are available), to amend the background forecast when it was mistrusted, to incorporate information not fed directly into the analysis scheme (e.g. from satellite cloud photographs), and to reject or amend data regarded as erroneous.

These processes have been developed gradually over recent years, and this development will be a source of inhomogeneity in the data set. Moreover, although since 21 August 1975 grid-point values have been extracted automatically and objectively from the daily analyses of the 10-level model, previously they were extracted manually from forecasters' daily hand-drawn charts. A 23-day comparison of the two methods by Folland (1975) showed no serious differences, but areas singled out for possible errors or inconsistencies were the North Pole, the east Pacific, North Africa and Arabia, and the Asian highlands—all of which feature later in this paper.

The radiation scheme of the model forecast was changed at the beginning of 1978.

The UK values for 1964 are in fact derived from the GWL and comparison revealed that the corresponding UK analysis is identical with that published by the Deutscher Wetterdienst.

(ii) *German Federal Republic.* The GWL values are based on daily 00 GMT analyses. The analysis scheme has been automated since the beginning of 1969. No details are published of human intervention, or of the use of forecast fields for guidance in analysis.

(iii) *USSR.* According to the preface to the 1976 and 1977 *Synoptic Bulletins*, 'the maps were constructed using CLIMAT TEMP data' (which are monthly mean ascents transmitted from stations).

'Over poorly covered areas of the northern hemisphere these maps were supplemented with data meaned over the month at the nodes of a regular standard geographical grid (with a north–south step of 5° and an east–west step of 10°), which were obtained from daily surface charts and maps of the upper-air pressure topography for 00.00 hours GMT. As the maps were analysed these data were subjected to a correction determined taking account of the magnitude of the difference between the values of the meteorological element at the nodes and at a nearby station (no more than 500 km away), using CLIMAT TEMP data.' The last sentence is not included in the prefaces to the 1973, 1974 and 1975 bulletins. No details are given of human intervention, or of use of forecast fields to assist the daily analyses.

(iv) *USA*. According to Colucci and Bosart (1979) the 6-layer primitive equation model at the National Meteorological Center was replaced in January 1978 by a 7-layer model of higher horizontal resolution. The former model appears to have been operational throughout the period (1973–77) studied here, but clearly the results obtained may not apply to more recent months when the new model was used. Again no details are provided of human intervention procedures, or of the use of forecast fields in analysis. In addition, no indication is given on the monthly analyses whether the data times are 00 or 12 GMT or both.

(c) *Missing values*

The UK and Grosswetterlagen analyses for 1964 are largely missing over the Pacific, at 20°N over Africa and Asia, and at 30°N over eastern Asia. For 1965 and 1966 the GWL analyses have similar coverage to that of 1964, but the UK analyses, although still omitting much of 20°N, are complete further north except at 30°N over part of the Pacific. From 1967 to 1979 the GWL analyses are virtually complete except for parts of 20°N, mainly over the Pacific. The UK analyses have similar coverage from 1967 to 1972 but are complete from 1973.

The USSR analyses are complete for the period studied, 1973 to 1977.

The USA analyses for 1973 to 1977 do not include part of southern Asia at 20°N, and sometimes it is impossible to extract grid-point values for 30°N over the Asian highlands.

3. Results

(a) *Difference maps*

(i) *UK versus Grosswetterlagen*. Following the separation of the data sources at the end of 1964, the differences in analysis increase not suddenly but gradually until for 1967 the UK-analysed 500 mb geopotentials are greater than the GWL values over most of the area considered, especially North Africa and southern Asia (Figure 1(a)). Similar discrepancies prevail up to 1974 but for 1975 the UK analysis is lower over part of the eastern Pacific. Over the North Pole, the UK analysis begins to be higher than GWL for 1975, and for 1976 this feature is marked, as are extreme differences over North Africa and Arabia (Figure 1(b)); 1977 has an extreme discrepancy of 60 gpm in 500 mb geopotential over the North Pole. For 1000 mb–500 mb thickness this is equivalent to 3 °C. By 1978 the North Pole discrepancy has eased but there are marked differences over the Asian highlands and the eastern Pacific (Figure 1(c)).

The individual monthly 500 mb geopotential difference charts often show discrepancies much larger than the annual charts. Figure 1(d) illustrates a recent 70 gpm disagreement over the Atlantic.

Analyses of 1000 mb–500 mb thickness have been used to produce a chart of relative thickness analysis change since 1973 (Figure 1(f)). It is evident that a British researcher into climatic change would

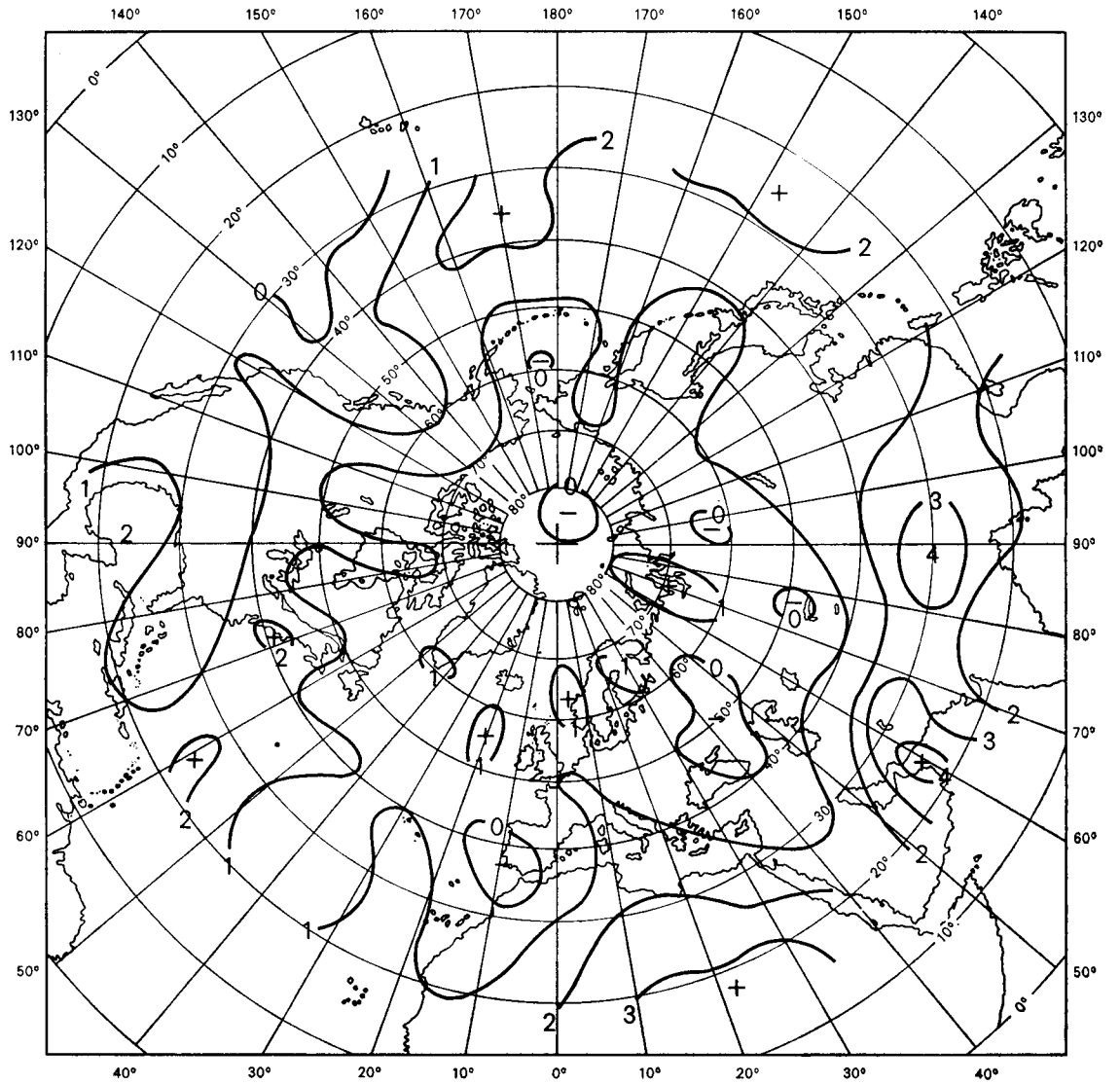


Figure 1(a). Annual mean 500 mb geopotential difference in decageopotential metres. United Kingdom minus Grosswetterlagen (GWL) for 1967, 00 GMT data.

be more likely than a Deutscher Wetterdienst researcher to deduce that the Arctic is warming and the subtropics cooling—and would produce 'facts', or so-called 'data', in support.

(ii) *UK versus USSR.* Comparison of UK and USSR analyses reveals differences of a similar magnitude to those between UK and GWL, but sometimes of the opposite sign. Figure 2(a), like Figure 1(f), is a chart of spurious climatic change, but for 500 mb geopotential. It has similar features, but they are less marked.

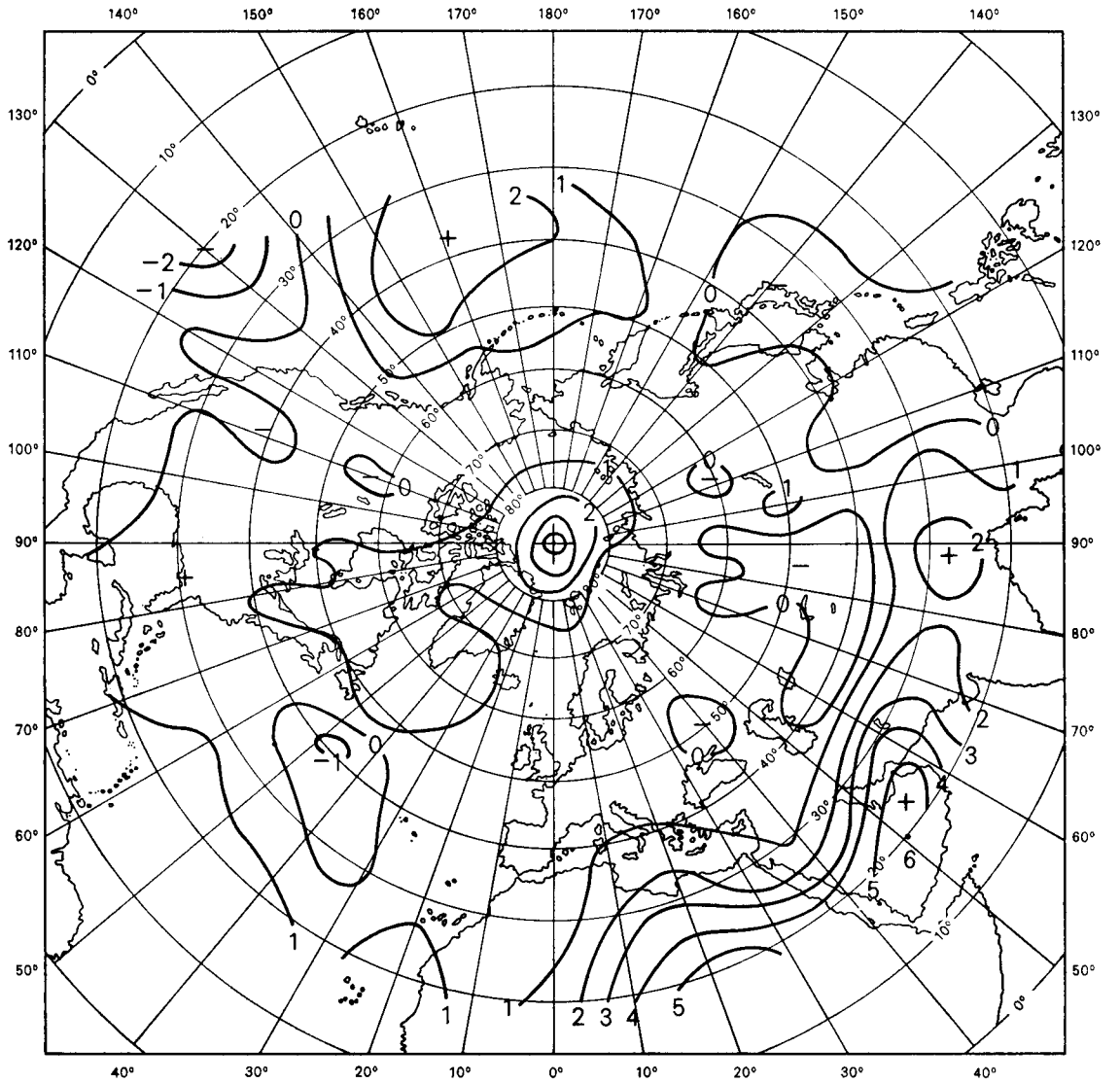


Figure 1(b). Annual mean 500 mb geopotential difference in decageopotential metres. UK minus GWL for 1976, 00 GMT data.

The most extreme monthly difference found is 120 gpm between UK and USSR 500 mb geopotentials over the North Pacific for January 1977 (Figure 2(b)).

(iii) *USA versus USSR.* As stated above, 700 mb geopotential had to be used for these comparisons. The disagreements became smaller in 1977, but even this recent reduction can be interpreted spuriously as climatic change (Figure 3). The effect of a change of layer mean temperature on 1000 mb–500 mb thickness is 1·9 times that for 1000 mb–700 mb thickness, so the contours in Figure 3 are at half the interval of those in Figures 1(f) and 2(a) to give visual comparability in terms of temperature.

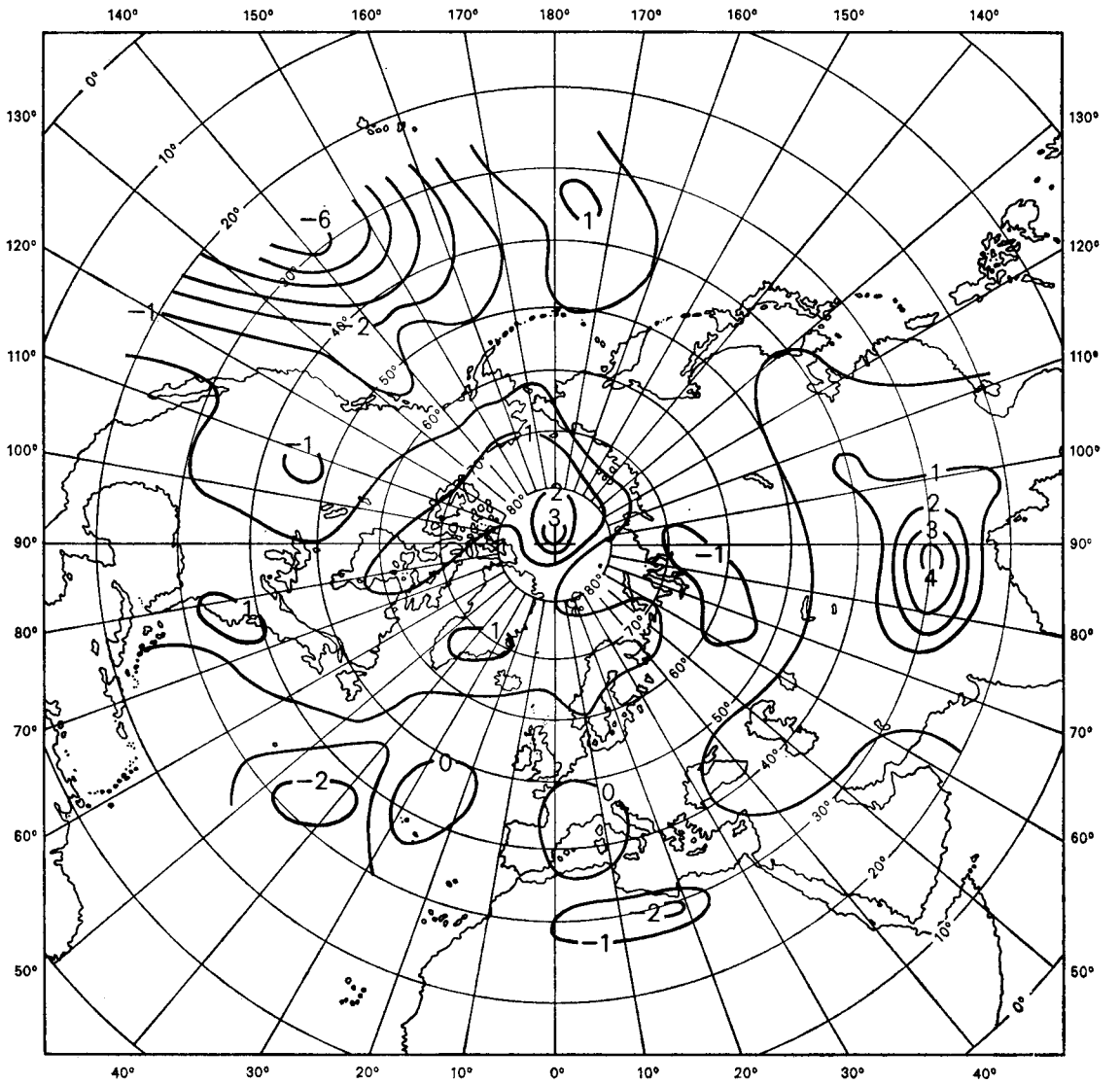


Figure 1(c). Annual mean 500 mb geopotential difference in decageopotential metres. UK minus GWL for 1978, 00 GMT data.

(b) *Sequences of differences at fixed points*

Figure 4 presents monthly sequences for 1973 to 1977 of 500 mb geopotential differences, UK minus GWL, at several fixed points. Because the difference maps are spatially coherent, nearby grid points have similar sequences of differences. Some points (e.g. 60°N 70°W) show a consistent slight difference. Others undergo one or two changes which are sudden (e.g. the North Pole) or gradual (e.g. 30°N 90°E).

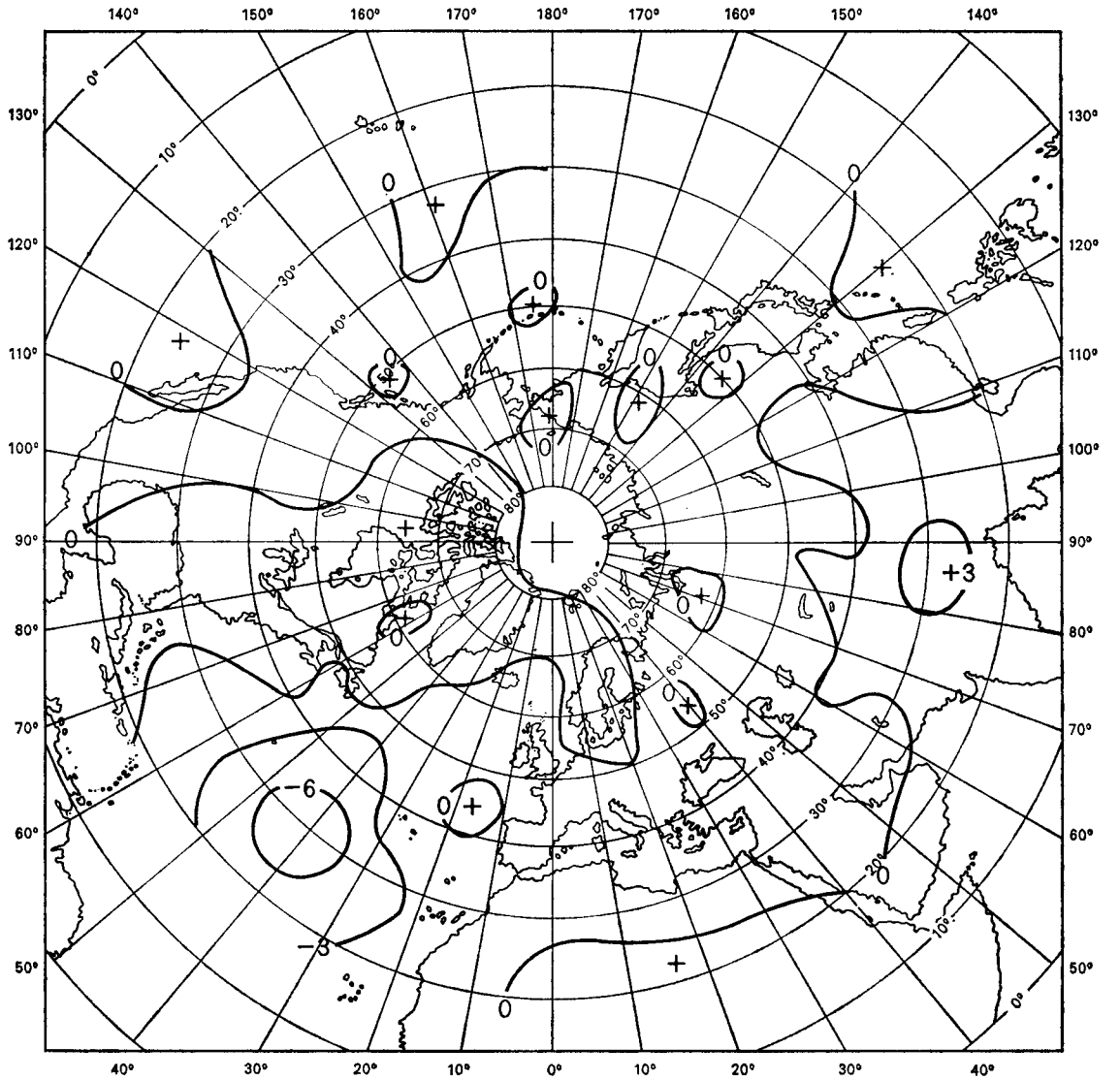


Figure 1(d). 500 mb geopotential difference, UK minus GWL, for July 1979, 00 GMT data. Contours at intervals of 3 decageopotential metres.

At 40°N 140°W there is an apparent annual cycle of differences. At 20°N 50°E the recent marked changes do not conform to an annual cycle.

For the same period for UK minus USSR, the increase at the North Pole is gradual, and there is no systematic trend at 30°N 90°E. The mid-Pacific still has an annual cycle and so do several points at 20°N, mainly for the more recent years. There are several cases of steady systematic differences, e.g. about −25 gpm at 30°N 40°W.

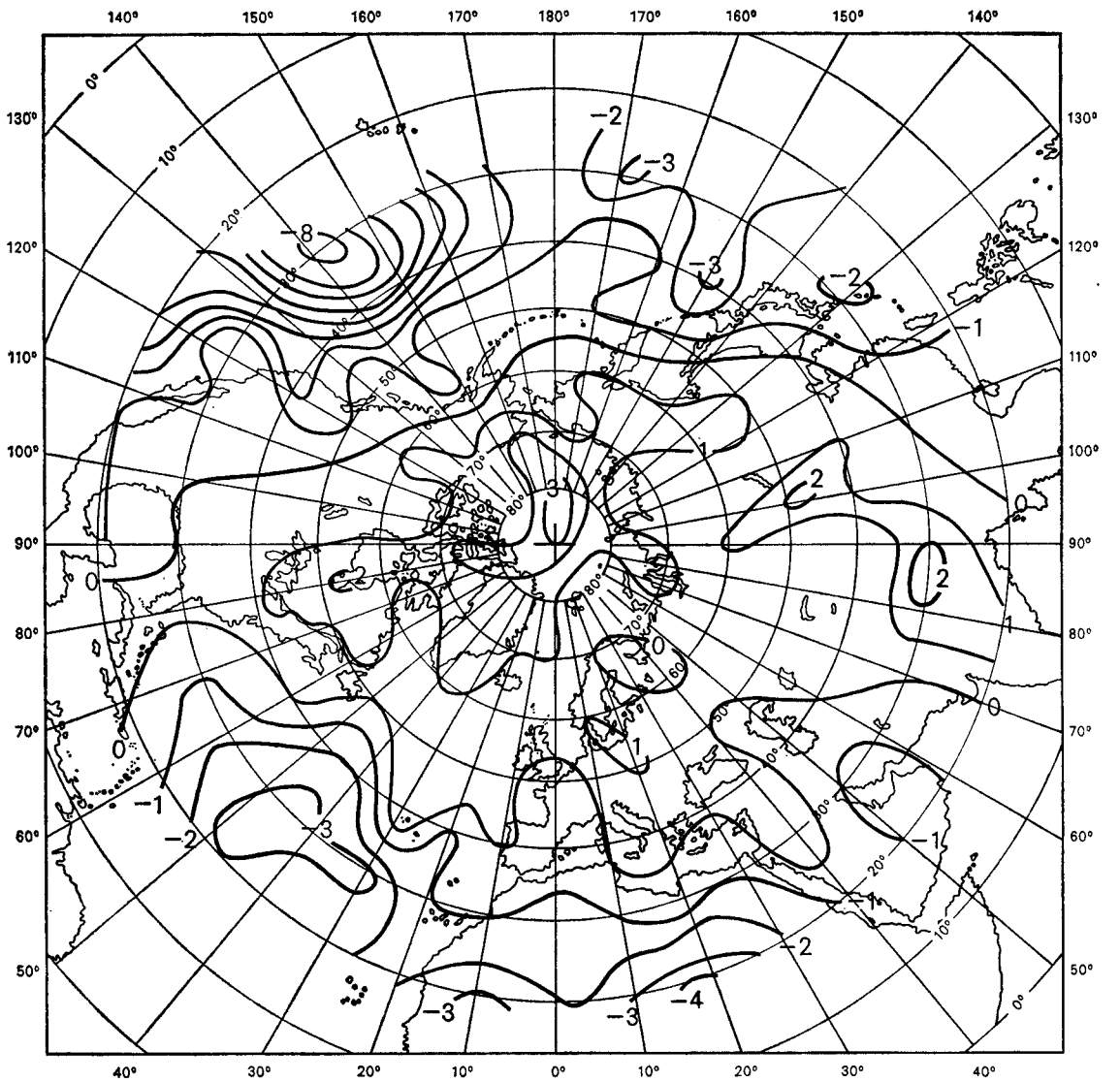


Figure 1(e). Annual mean 1000–500 mb thickness difference in decageopotential metres. UK minus GWL for 1978, 00 GMT data.

USA minus USSR 700 mb geopotential for 1973 to 1977 varies irregularly at the North Pole. There is a systematic decrease of 50 gpm at 20°N 130°W and a consistent −25 gpm difference at 20°N 20°E. There are no clear-cut annual cycles except to some extent at 40°N 160°W.

(c) *Zonal annual mean differences*

Climatic change is often monitored in terms of zonal averages. The changes in zonally averaged

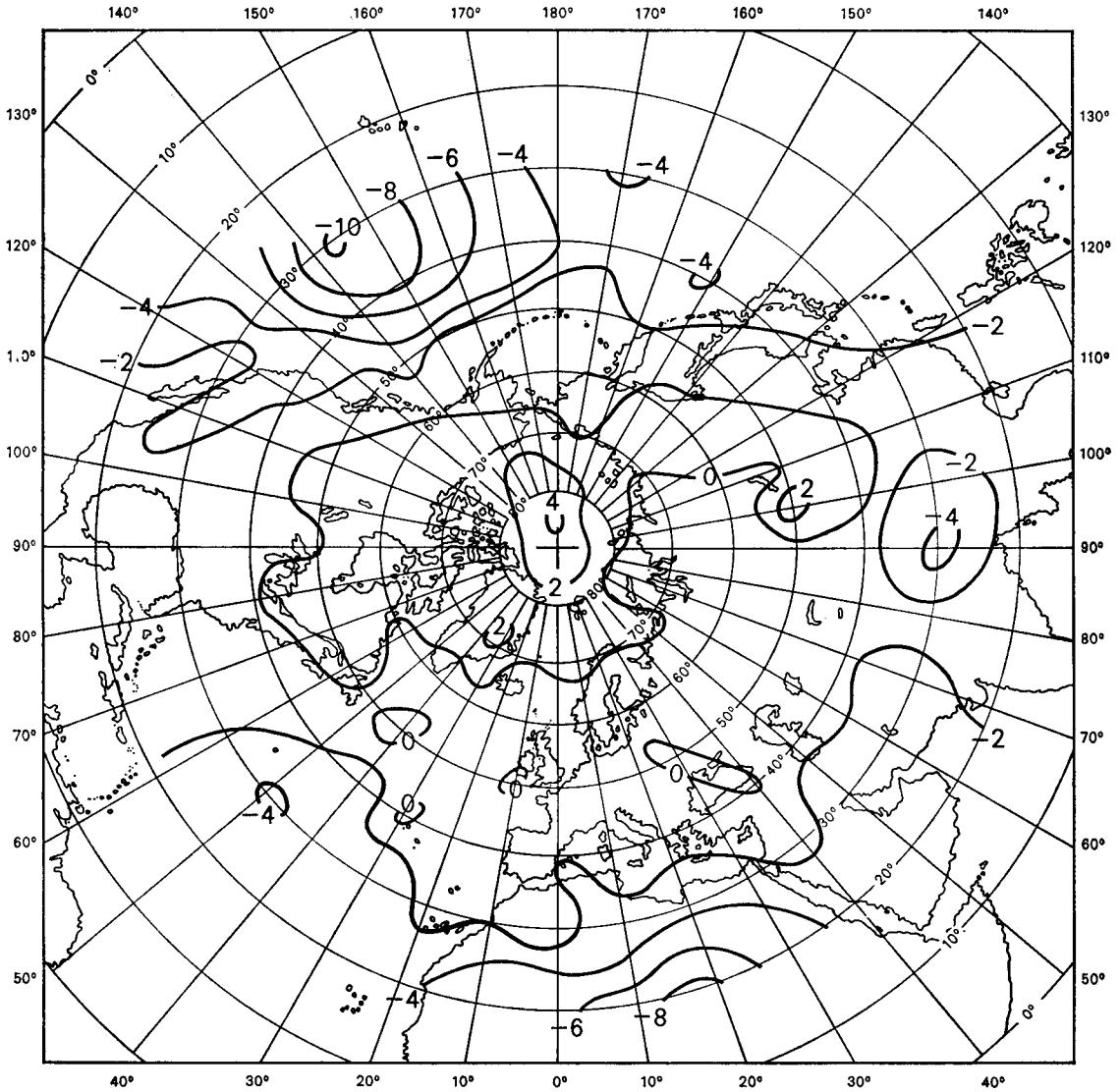


Figure 1(f). Annual mean 1000–500 mb thickness, 1978 minus 1973, UK analyses minus GWL analyses, for 00 GMT. Contours at intervals of 2 decageopotential metres.

annual UK minus GWL 500 mb geopotentials for 1964 to 1978 are shown in Figure 5. Clearly there are large changes at 20°N and 30°N and near the North Pole, but even mid-latitudes are not immune, showing a relative reduction of UK geopotentials in the most recent years. The changes in 40°N minus 60°N 500 mb geopotential differences are unsystematic and correspond to geostrophic wind differences of less than 1 m/s.

Trends in low latitudes and near the North Pole are also characteristic of the 1973 to 1977 zonally averaged annual UK minus USSR 500 mb geopotentials and USA minus USSR 700 mb geopotentials.

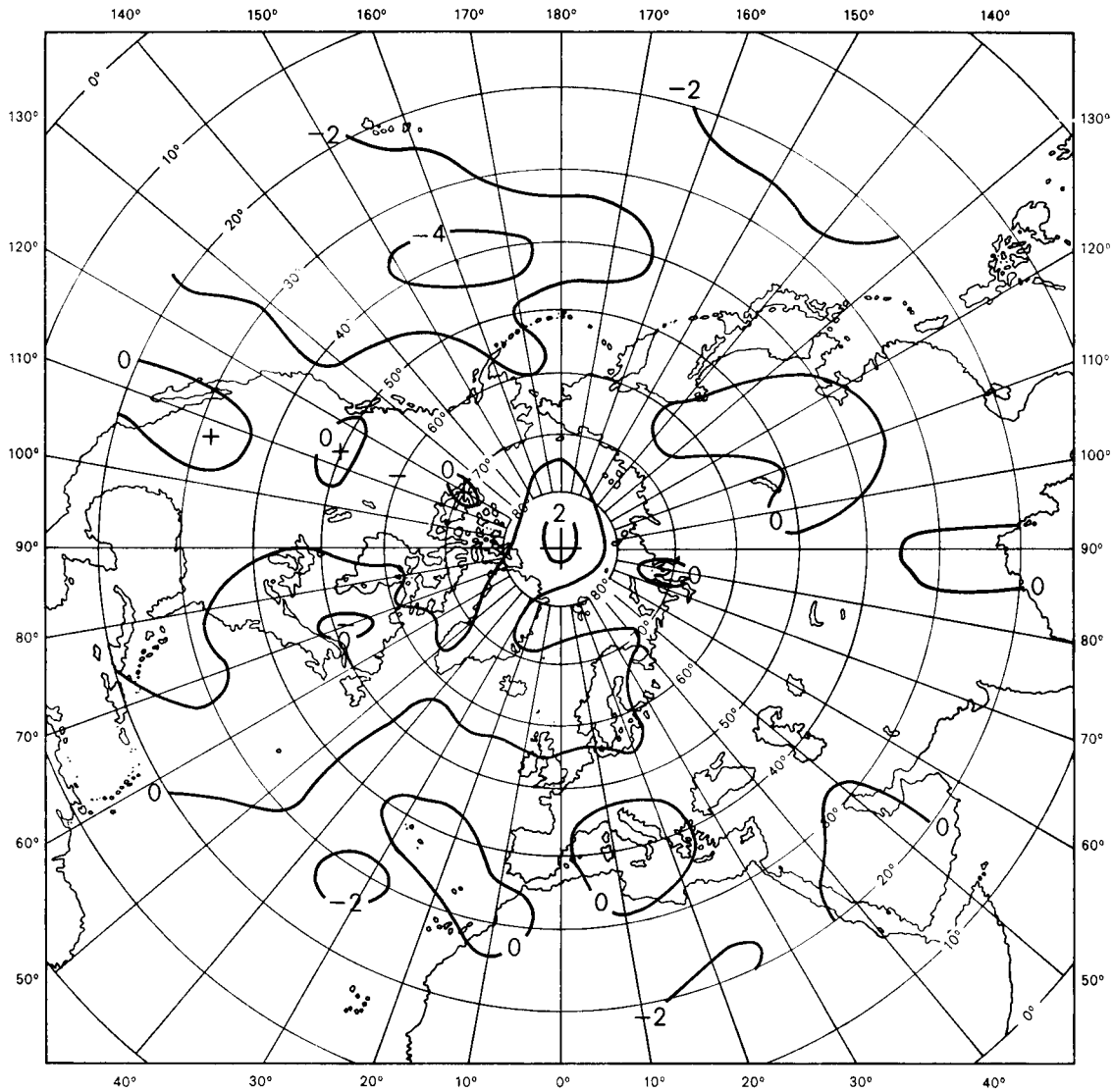


Figure 2(a). Annual mean 500 mb geopotential, 1977 minus 1973, UK minus USSR analyses, for 00 GMT. Contours at intervals of 2 decageopotential metres.

(d) *Areal annual mean differences*

Figure 6(a) summarizes the changes in the annual geopotential differences averaged over the whole analysis area. The zonal means are weighted according to the cosine of the latitude (cosine 80° is used for the North Pole). The weights have been multiplied by the proportion of coverage of grid-point values at that latitude. The USA minus USSR 700 mb geopotential differences have been multiplied by 1·9 as a means of converting them to effective 500 mb geopotential differences.

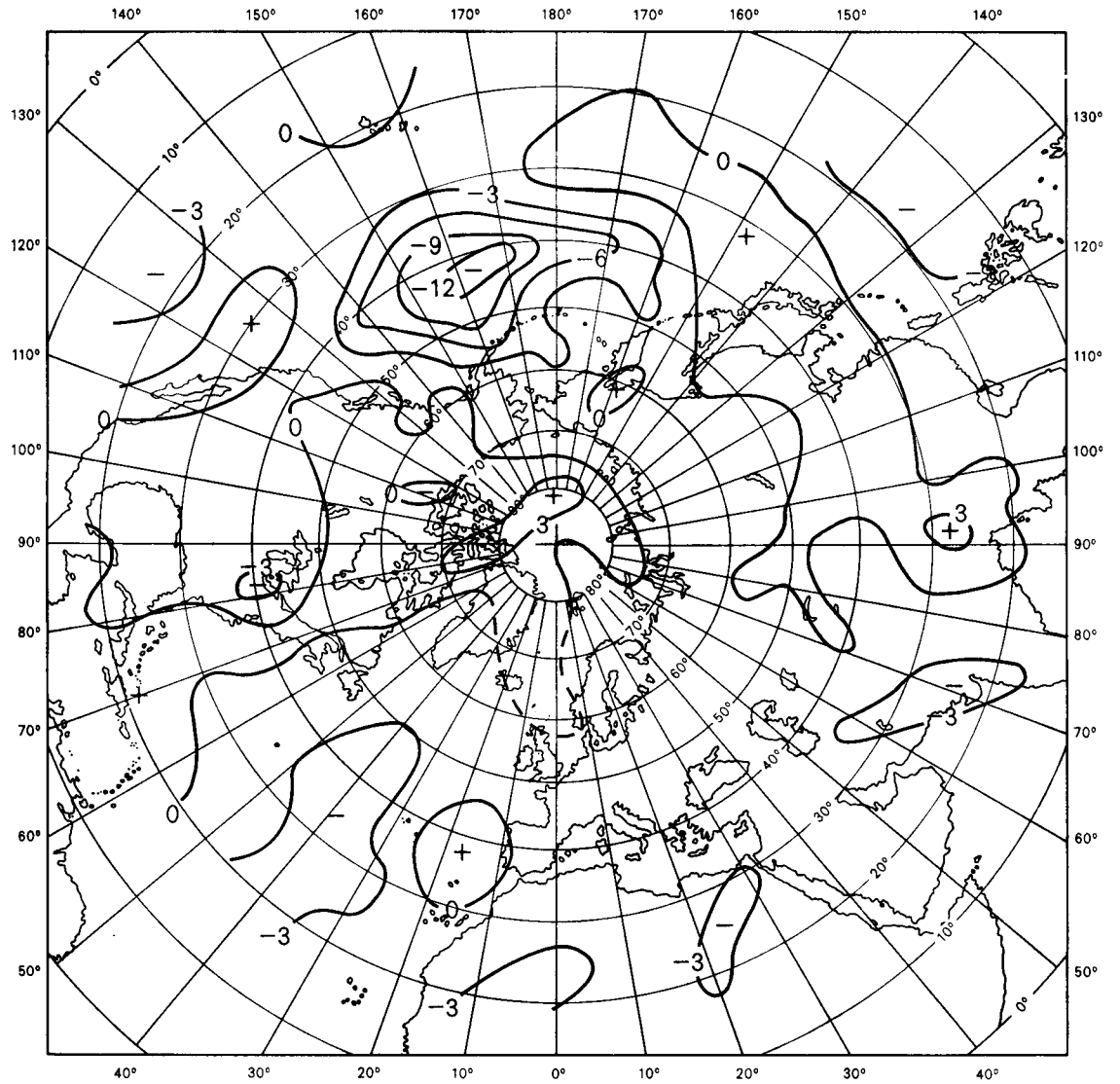


Figure 2(b). 500 mb geopotential difference, UK minus USSR, for January 1977, 00 GMT data. Contours at intervals of 3 decageopotential metres.

The geopotential scale in Figure 6(a) includes an effective temperature scale which applies if the differences are assumed to be the same for 1000 mb to 500 mb thickness. The recent trends of the differences are of the order of 0·5 °C in these terms.

(e) *Annual thickness or temperature equivalents*

Figure 6(b) presents the annual areal mean 1000 mb–500 mb thicknesses for 1973 to 1978 as derived

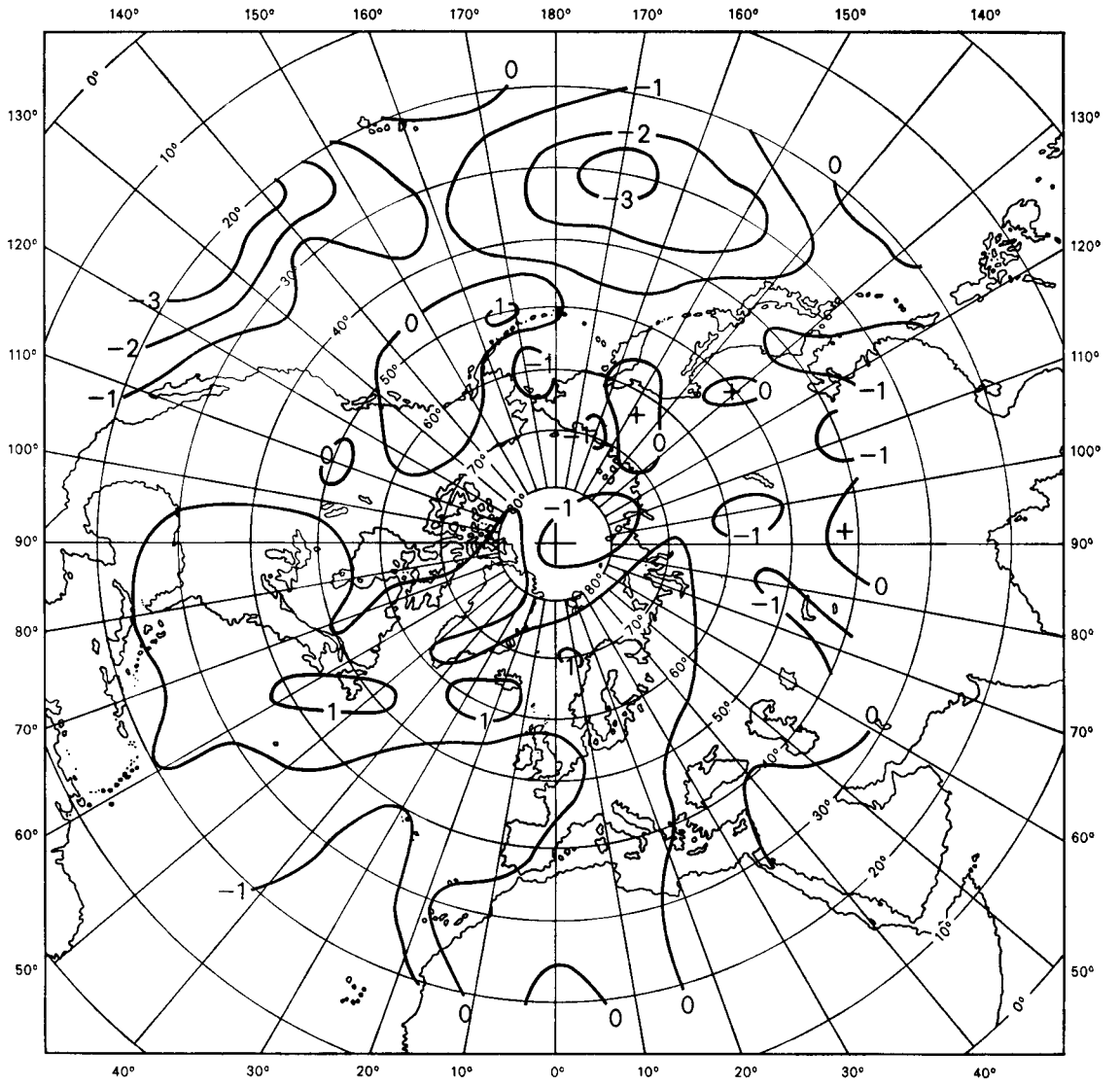


Figure 3. Annual mean 700 mb geopotential, 1977 minus 1973, USA analyses minus USSR 00 GMT analyses, in decageopotential metres.

from the UK analyses for the whole analysis area. The estimated GWL and USSR thicknesses have been derived from these by subtracting the areal annual mean 500 mb geopotential differences. The estimated USA thicknesses have been derived from the estimated USSR thicknesses by adding 1·9 times the areal annual mean USA minus USSR 700 mb geopotentials.

The conclusion is obvious: we can detect interannual warmings and coolings, whether they are real or of instrumental origin or due to geographically biased data. But the changes in the analysis differences

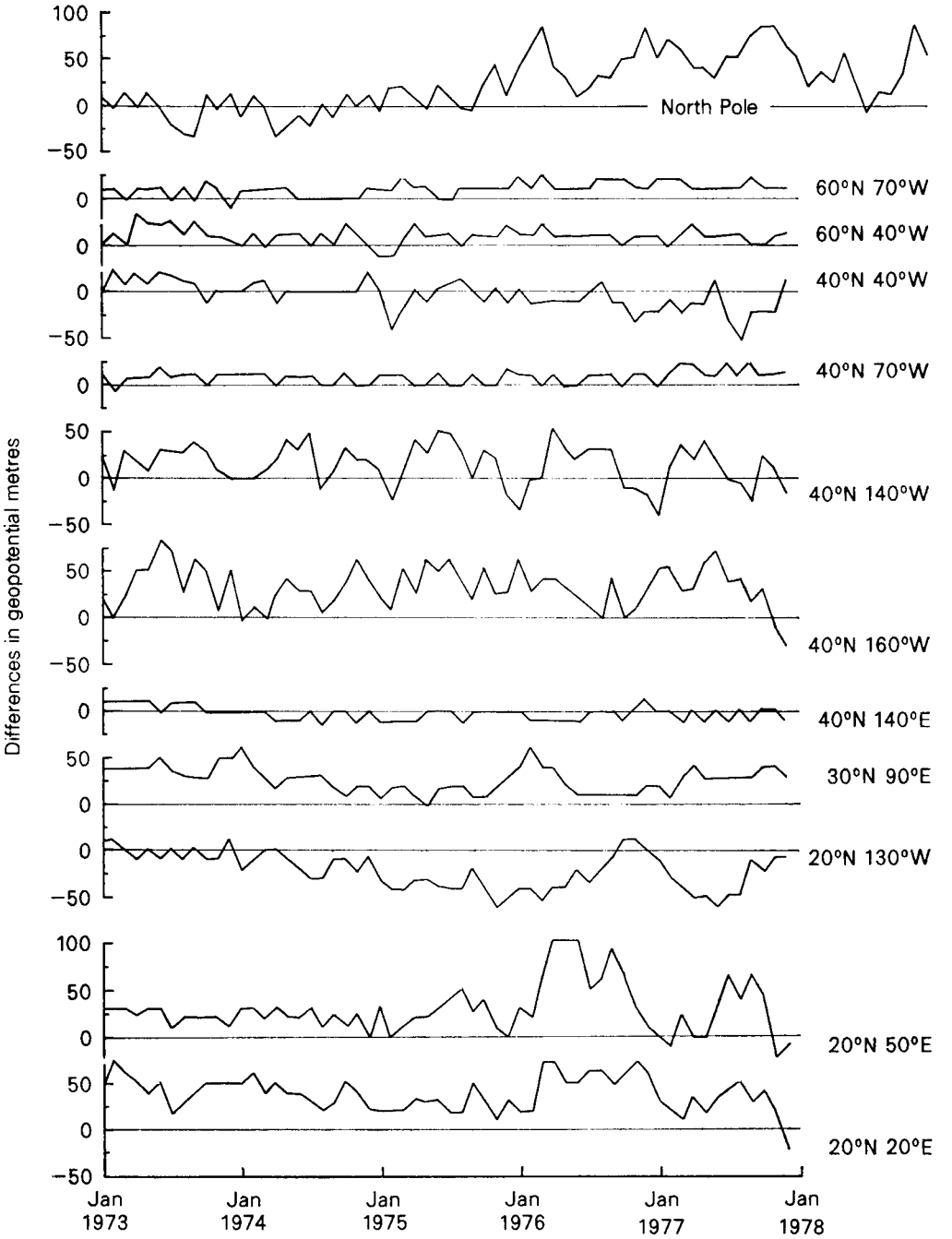


Figure 4. Monthly mean 500 mb geopotential differences, UK minus GWL analyses.

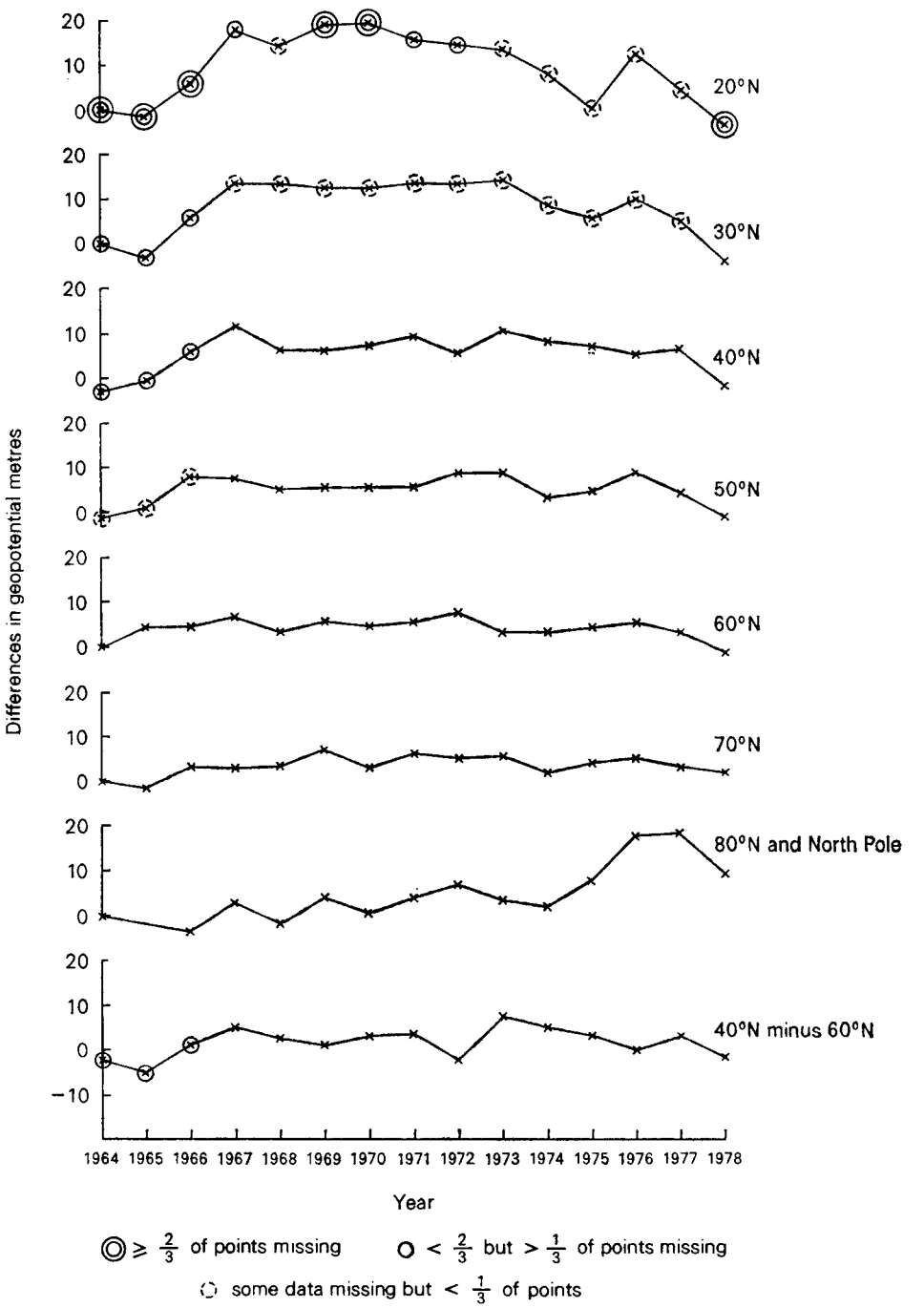


Figure 5. Zonal annual mean 500 mb geopotential differences, UK minus GWL analyses.

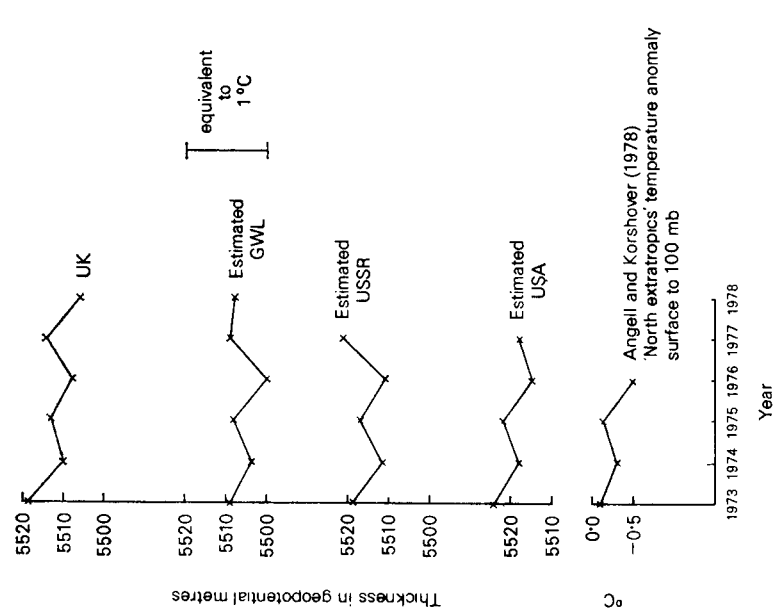


Figure 6(b). Annual mean thickness of the 1000–500 mb layer, areally meaned from 20°N to the North Pole.

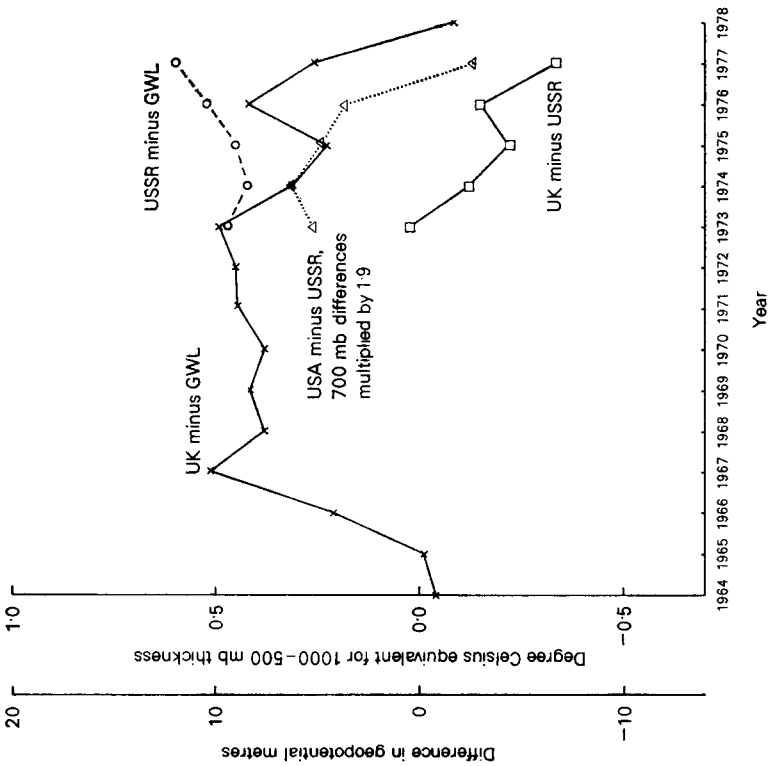


Figure 6(a). Annual mean differences between national 500 mb geopotential analyses, areally meaned from 20°N to the North Pole. *Note.* Until 1972 inclusive, and in 1978, much of 20°N was missing. Until 1966 inclusive much of 30°N and 40°N were missing.

are large enough to swamp any subtle climatic trends for the hemisphere. Has it cooled, as the UK and USA graphs suggest, or has the cooling been arrested as indicated by GWL and the USSR?

Figure 6(c), derived in the same way as Figure 6(b), shows that the relative trends in 1000 mb to 500 mb thickness are largest at 20°N and in the Arctic and least at 50°N and 60°N. Concern about warmings and coolings in the Arctic, if regarded as being precursors of changes elsewhere, needs to be matched by great care in using the data.

(f) *Seasonal trends*

Zonally and areally meaned 500 mb geopotential differences for January and July for UK minus GWL (not shown) display trends which are similar to one another and to the annual trends in Figures 5 and 6(a), though in summer the decrease in the subtropics is later and more sudden. The UK minus USSR differences change much less markedly in summer than in winter. The USA minus USSR differences behave differently in the opposite seasons but the variations in summer are only a little less marked than in winter.

Sequences of January and July zonally and areally meaned 1000 mb–500 mb thicknesses, derived in the same way as in Figures 6(b) and 6(c), but not illustrated here, show best agreement between analyses in mid-latitudes and poorest in the subtropics, with changes of differences between analyses still swamping any real climatic change which may have occurred for the composite area 20°N to the North Pole.

(g) *Comparison of trends and changes of annual mean thicknesses with results of other workers*

Figure 6(b) includes temperature anomalies for 1973 to 1976 for the northern hemisphere extra-tropical latitudes, derived from Angell and Korshover (1978). It should be noted that Angell and Korshover's results are for the surface to 100 mb and are for stations (not grid points) north of 30°N, and mainly north of 40°N. The results are more like the thickness series for GWL and USA than the other two series. The presentation of their results in Figure 6(b) was derived by averaging their four seasonal temperature anomalies which they had already time-smoothed. Because the winter season overlaps the turn of the year, the annual values attributed to Angell and Korshover in Figure 6(b) refer to the 12 months beginning with December of the previous year.

Figure 6(d) presents surface to 100 mb temperature anomalies for 1964 to 1976 for the north subtropics (stations mostly near 20°N), the north temperate zone (stations mostly near 50°N) and the north polar zone (stations mostly near 70°N), derived from Angell and Korshover (1978) in the same manner as for Figure 6(b). The north subtropics series is similar to the 30°N series in Figure 6(c) but with some marked disagreements, e.g. having 1968 colder than 1967. The north temperate time series has smaller recent fluctuations than the 50°N series, but they are in phase. The north polar series parallels the 70°N to North Pole series during 1968–73 but bears little relation to it outside this period, or to the '70°N only' series added to Figure 6(c) in order to allow a more direct comparison.

Figure 6(e) compares annual mean temperatures of the 1000 mb–500 mb layer at high latitudes for 1973 minus 1949 presented by Dronia (1974) with values computed from the UK grid-point data, used by Painting (1977). The greater relative cooling according to Dronia is consistent with Figure 6(c): Dronia used GWL grid-point values.

In conclusion, the general similarity of the results of Angell and Korshover to those obtained from grid-point values shows that uncertainties of analysis have not overridden the information contained in the original data; but the differences between the various estimates make it impossible as yet to resolve hemispherically meaned climatic trends. Moreover, any systematic instrumental changes in the instrumental data may have contaminated all the estimates to a similar but unknown (though not unknowable) degree.

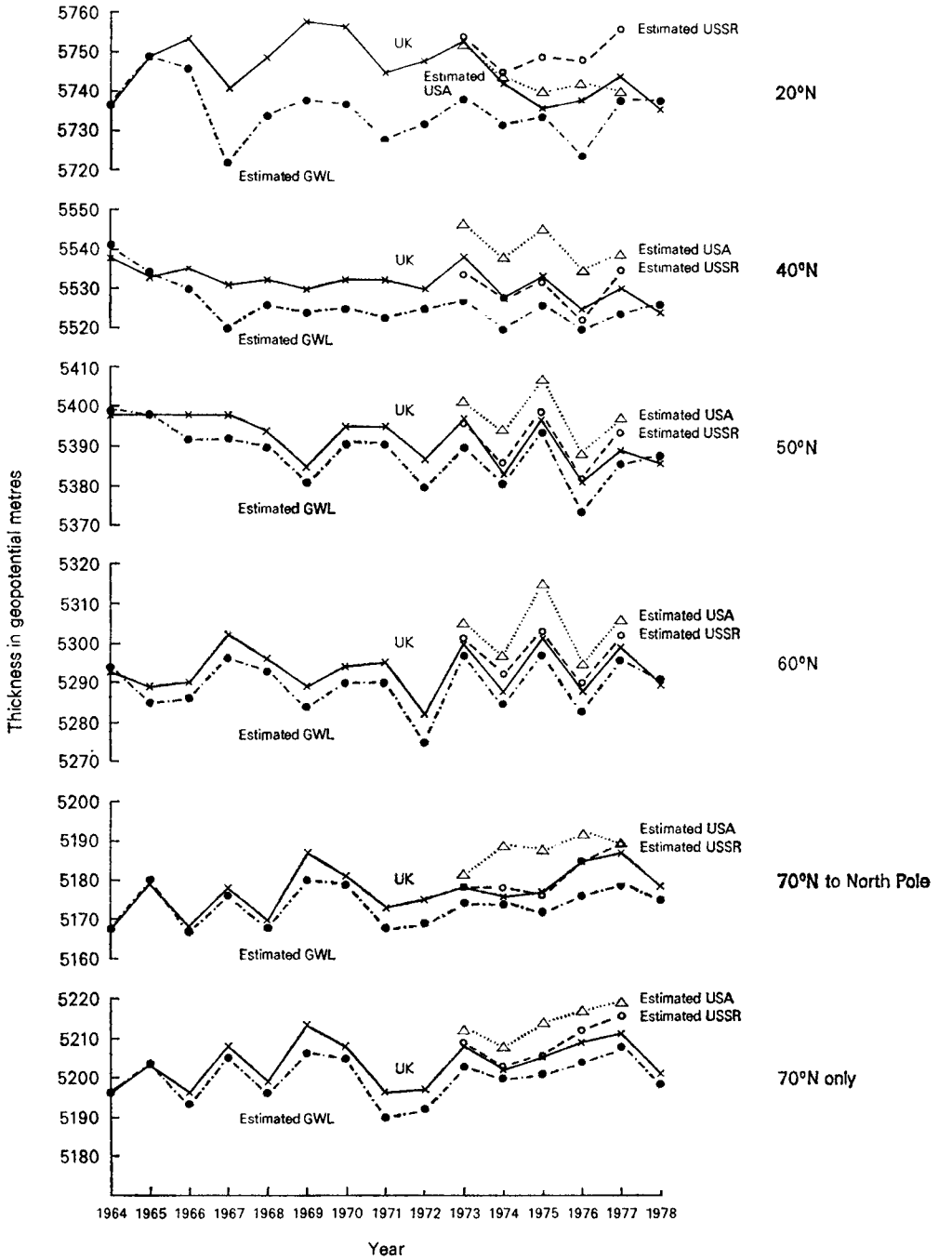
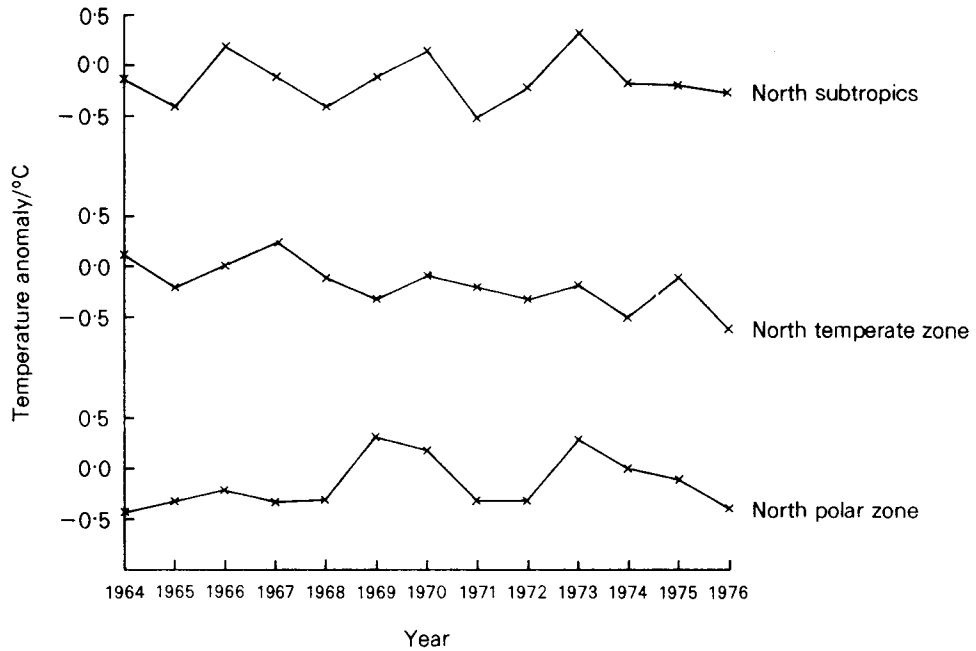


Figure 6(c). Annual mean thickness of the 1000–500 mb layer.



Figures 6(d). Annual mean temperature anomalies of the surface to 100 mb layer (K), after Angell and Korshover (1978).

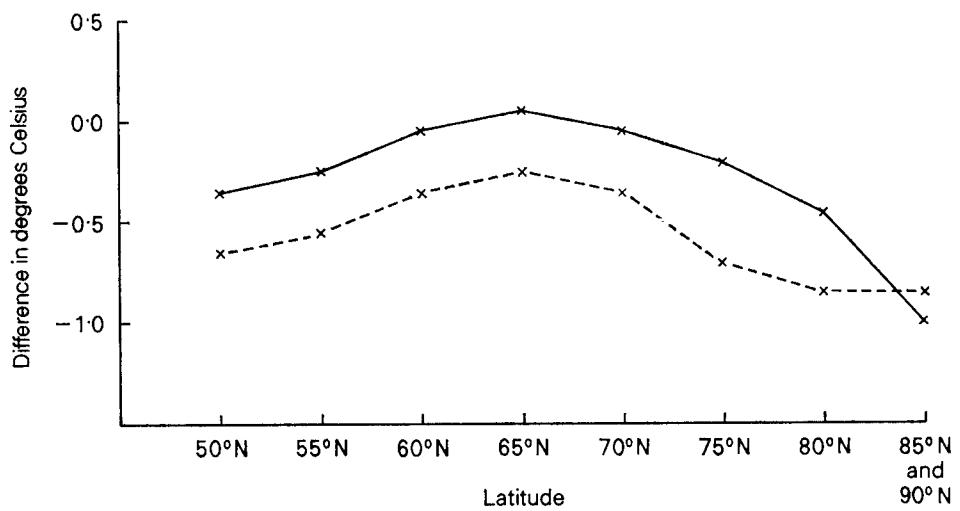


Figure 6(e). Annual mean temperature of the 1000–500 mb layer (K), 1973 minus 1949.
x - - x Dronin (1974) X——X UK grid-point data (used by Painting (1977)).

4. Causes of the disagreements

4.1 *General considerations*

The following must be considered as possible general reasons for the discrepancies between the different nations' analyses.

(i) The data bases of the daily analyses may have differed. Data from different radiosonde stations may have reached different analysis centres. Moreover different quantities of satellite and aircraft data may have been employed.

(ii) Different radiation corrections may have been applied to the same radiosonde data at the different analysis centres.

(iii) Earlier daily analyses may have been subjective; the later ones are more likely to have been made objectively but with some subjective intervention including the rejection or amendment of data considered to be in error.

(iv) Objective analysis schemes have certainly differed between analysis centres and have probably been amended progressively. If the first-guess field used in the analysis routine was a forecast derived from earlier fields, it will have depended on the model used. The horizontal resolution, interpolation scheme, and the incorporation of dynamical constraints (connecting e.g. heights and winds) will have varied from model to model.

Rinne and Frisk (1979) have computed the development of the analysis error of the 500 mb geopotential during 1946 to 1969, assuming optimum interpolation of the data from the radiosonde network with specified realistic observation error and estimated first-guess forecast-field error. Their areas of maximum estimated error are remarkably consistent with the areas where marked disagreements between analyses appear in Figures 1–3.

(v) Estimates of the effective mean sea level pressure for mountainous areas will have depended on the model or reducing equation used. Absolute geopotentials at pressure surfaces will have been affected more than thicknesses.

(vi) Annual cycles of analysis differences over mid-Pacific will have been caused by the diverse effects ont he different analysis schemes of the real annual cycle of atmospheric geopotential fields. Over land, annual cycles of differences are more likely to have resulted from differing treatments of radiation corrections, which have an annual cycle.

(vii) The high UK values over the North Pole are thought to have resulted from a tendency, reflected in the background fields, for the model to forecast excessively high values there. The appearance of this discrepancy in 1975, when analyses from the model became the basis of the grid-point values, is consistent with this explanation. The slightly high UK values, relative to GWL, in recent years over eastern North America may have resulted from erroneous application of radiation corrections in the United Kingdom.

4.2 *Specific example*

The worst case of disagreement is a difference of 150 gpm between GWL and USSR 500 mb geopotentials for 40°N 170°W on the monthly chart for January 1977. This point is one of the furthest from a radiosonde station, and is in a region of strong geopotential gradients especially in winter. It is therefore highly susceptible to variations in the method of analysis. The daily analyses made by the Deutscher Wetterdienst and the USSR in this area were examined, and the findings are given in Table I. This shows that the USSR analyses have stronger gradients around Aleutian lows of similar or lesser

Table 1. 500 *mb geopotentials at* 40°*N*, 170°*W during January* 1977. *Values are in decageopotential metres and are for* 00 *GMT.*

Date	Grosswetterlagen analysis		USSR analysis		Comments (see key below)
	Geopotential	Local synoptic pattern	Geopotential	Local synoptic pattern	
1	534	Flow from WSW.	549	Flow from SW.	(A)
2	533	Flow from SW.	542	Flow from SW.	(A)
3	531	Flow from SW.	531	Flow from SW.	
4	519	Troughing. Flow from W.	536	Flow from SW.	(A) USSR trough further west.
5	523	Flow from SW.	537	Troughing. Flow from SW.	(A)
6	520	Troughing. Flow from SW.	517	Troughing. Flow from SW.	USSR trough deeper.
7	534	Flow from W.	533	Flow from WSW.	
8	523	Troughing. Flow from SW.	524	Troughing. Flow from SW.	
9	519	Troughing. Flow from WSW.	530	Troughing, almost col. Flow from SW.	(A) USSR had extra low at 40°N 160°E.
10	521	Flow from SW.	532	Flow from SW.	(A)
11	510	Cyclonic. Flow from SW.	536	Troughing. Flow from W.	(A) USSR low further north.
12	519	Flow from WSW.	535	Flow from SW.	(A) A 20° difference in wind direction at station 70316 between analyses.
13	520	Flow for WNW.	545	Flow from WSW.	USSR low shallower and further north.
14	520	Flow from WNW.	543	Flow from W.	(B)
15	522	Flow from WSW.	535	Flow from SW.	(A)
16	515	Slight troughing. Flow from WSW.	526	Flow from WSW.	(A)
17	514	Flow from WSW.	531	Flow from SW.	USSR low shallower with stronger gradients round it.
18	515	Cyclonic. Flow from W.	539	Flow from WSW.	(B)
19	527	Trough to NE. Flow from WNW.	539	Troughing. Flow from SW.	(A) USSR had strong flow from SW where GWL had flat trough 45°–50°N 165°–170°W.
20	526	Trough slightly to E. Flow from WNW.	528	Trough slightly to W. Flow from WSW.	
21	526	Flow from W.	524	Shallow trough to W. Flow from WSW.	
22	527	Flow from SW.	544	Flow from WSW.	(A)
23	512	Sharp troughing. Flow from SW.	539	Flow from SW.	(B) USSR had strong flow from SW where GWL had trough.
24	512	Cyclonic. Flow from W.	549	Trough to W. Flow from SW.	(D) USSR had strong flow from SW where GWL had low. USSR had extra low 30°N 175°W.
25	530	Trough to W. Flow from WSW.	542	Trough to E. Flow from W.	(C)
26	517	Cyclonic. Flow from SW.	525	Cyclonic. Flow from SW.	USSR low further NW, deeper, with much stronger gradients round it.
27	510	Cyclonic. Flow from SW.	520	Cyclonic. Flow from SW.	USSR low further NW with slightly stronger gradients round it.
28	521	Cyclonic. Flow from NW.	532	Cyclonic. Flow from WNW.	USSR low further north with slightly stronger gradients round it.
29	537	Ridge to W. Flow from WNW.	549	Flow from SW.	(C)
30	542	Ridge to E. Flow from WSW.	534	Ridge to W. Flow from WNW.	USSR low slightly deeper and further south.
31	517	Cyclonic. Flow from SW.	535	Cyclonic. Flow from SW.	USSR low shallower and further north-west.
Average	522·5		534·9		
	(monthly chart 522)		(monthly chart 537·5)		

Key to Comments: (A) USSR had stronger gradients around Aleutian low of similar depth, rendering peripheral values higher.
(B) USSR low shallower and further north with stronger gradients round it.
(C) USSR flow from SW extended further north into Grosswetterlagen low zone.
(D) Some questionable data.

depth than the GWL analyses, resulting in greater geopotentials in mid-Pacific. The cross-sectional shape of a depression on an analysis will be very sensitive to the incorporation of dynamical constraints and to the grid-resolution of the model: an observation of calm at the centre of a depression, coupled with a geostrophic constraint, will tend to cause the analysed geopotential or pressure at surrounding grid points to be nearly as low as the central value. Some analysts may also apply the same idea subjectively, whereas others (in this case apparently mainly in the USSR) may conceive depressions to have very small centres surrounded immediately by tight gradients. The problem would not arise if data were plentiful.

Figures 7(a) and (b) are the GWL and USSR analyses for 00 GMT on 24 January 1977, for which the analysed geopotential at 40°N 170°W (the large dot) differs by 370 gpm. The above-mentioned tendency for tighter gradients round USSR lows combines with some questionable data, and a general sparsity of information, to make the analyses totally different.

5. *Recommendations*

It has been shown that the combined uncertainties in data and in analytic techniques make it impossible to reach conclusions on recent trends of the mean temperature of the northern hemisphere, obtained from grid-point data sets. For the tropics and the southern hemisphere, where data are much sparser, the uncertainties must be much greater.

Two courses of remedial action present themselves. They could be followed simultaneously under the aegis of the World Climate Programme.

Firstly, it is proposed that a set of upper-air stations be selected for global climate monitoring. The upper-air data from these stations should be subjected to meticulous quality control, taking account of past changes of instruments and of observing procedure. The stations should be selected on the grounds of continuity of record and of good data quality. They should be as evenly spaced as possible and preferably juxtaposed, or nearly so, to surface stations having a long reliable record, the data from which should also be meticulously quality-controlled. The author has begun to make such a selection.

Secondly, since the best sets of fixed-station data cannot give a complete picture of world climatic change because of the gaps over the oceans, the above proposal should be complemented by the creation of an internationally agreed backdated grid-point data set covering upper-air and surface data for the atmosphere, and sea-surface temperature. The observations used to create the data set should be as complete as possible, and thoroughly quality-controlled, and the analysis procedure should take into account the structure of atmospheric fields in data-sparse areas.

The practical difficulties in agreeing on and creating such a data set may be formidable, but there appears to be no other way of obtaining a complete representation of climatic change.

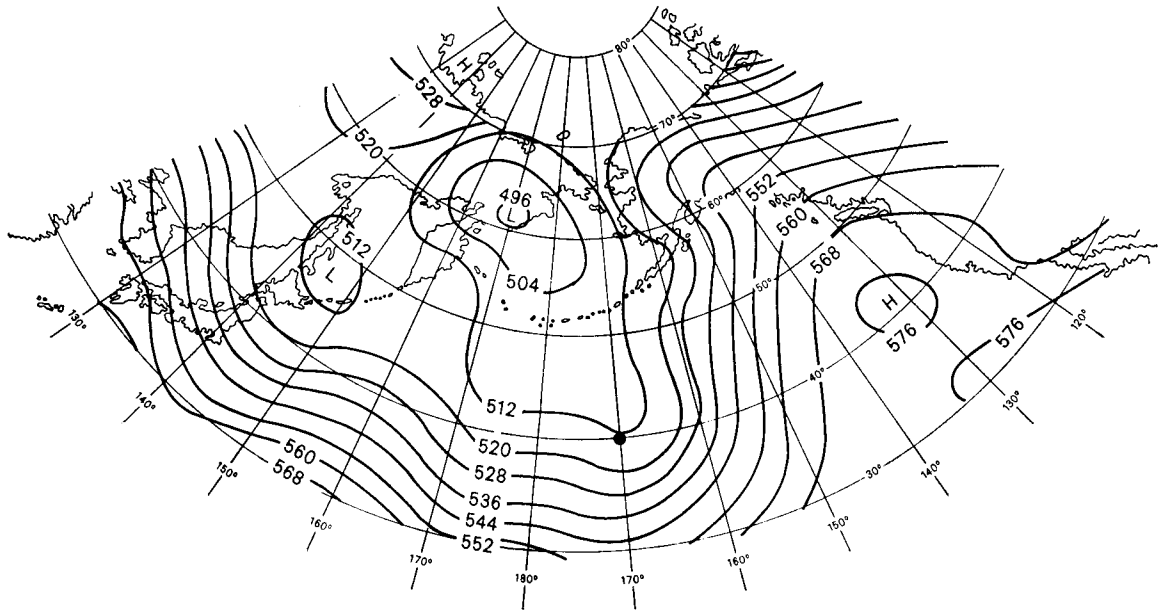


Figure 7(a). Deutscher Wetterdienst (GWL) 500 mb geopotential analysis for the North Pacific, 00 GMT, 24 January 1977. Isopleths at intervals of 8 decageopotential metres.

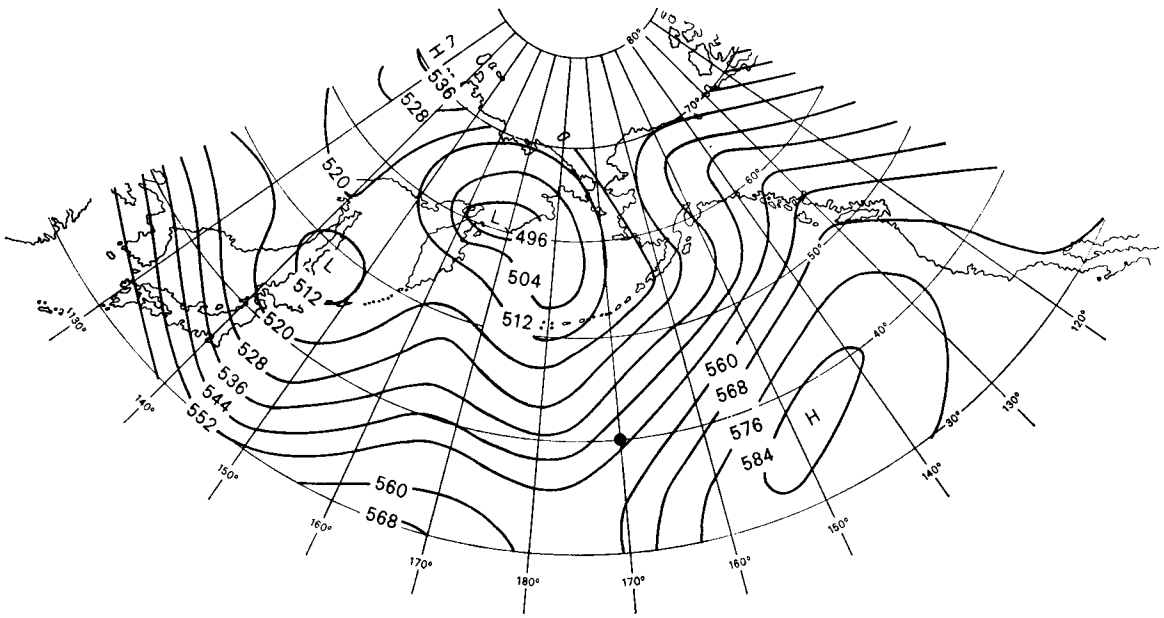


Figure 7(b). USSR 500 mb geopotential analysis for the North Pacific, 00 GMT, 24 January 1977. Isopleths at intervals of 8 decageopotential metres.

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551.577.21(425):551.577.34

A revised rainfall series for Spalding, Lincolnshire

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Summary

Two possible discontinuities in the rainfall series for Spalding published by Craddock and Wales-Smith (1977) are identified. Their removal reduces the considerable long-term variations in rainfall present in the original series, and secures much better agreement with other long rainfall records.

1. Introduction

Craddock and Wales-Smith (1977) produced a series of monthly rainfall totals representative of a site at Pode Hole, near Spalding in Lincolnshire, back to 1726. This record produced some marked changes in rainfall over the last 250 years which seem rather out of line with most other indications. This promoted an investigation into the Spalding record to see if evidence from other rain-gauges could help to resolve the differences.

2. Comparison with other long rainfall series

In Figure 1 decadal means of annual rainfall for the Spalding series are compared with those for three other rainfall records which go back into the first half of the eighteenth century. These are:

(i) The well-known series for England and Wales, first published by Nicholas and Glasspoole (1932) and since maintained by the Meteorological Office.

(ii) The record for Kew compiled by Wales-Smith (1980).

(iii) A series for Hoofddorp in The Netherlands, derived from data published by Labrijn (1946).

The data for Kew and Hoofddorp indicate a general absence of long-period trends, but the England and Wales series shows a marked increase in rainfall, while the graph for Spalding displays a strikingly concave form. The low rainfall totals indicated by the England and Wales series in the eighteenth century may not be real. During this period the number of gauges used was small, and their sites were unorthodox, with a preponderance of faults leading to an underestimate of the rainfall likely to be recorded by a

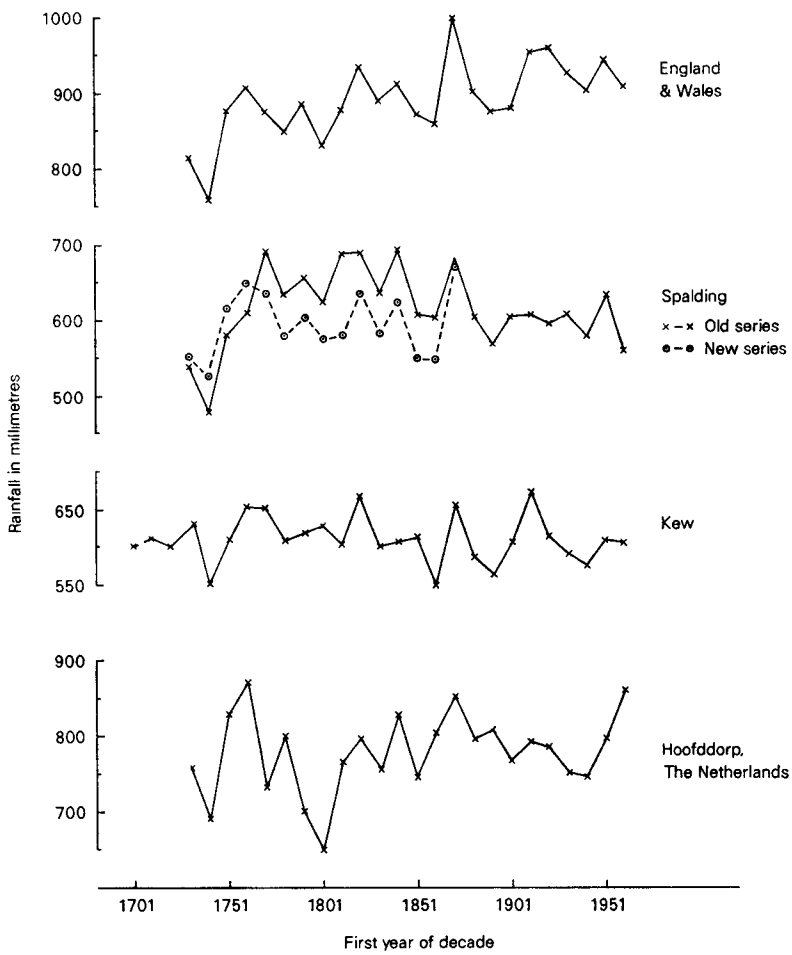

Figure 1. Decadal means of annual rainfall for four long rainfall series.

modern gauge. In 1820 the number of stations available reached 17, and for the first time mapping techniques could be used to calculate the areal rainfall. Only from this date can the England and Wales series be regarded as reliable. The concave nature of the Spalding record may be largely attributed to a period between about 1770 and 1870, which, in comparison with the other records, was too wet.

A closer examination of the period since about 1850 is made in Figure 2, where decadal means of annual rainfall at Spalding are compared with decadal means for other stations in eastern England. These latter are mainly unpublished series made homogeneous by the author. Also included is a series for the location 53°N 0°W, very close to Spalding and not very far from Mansfield, obtained from data

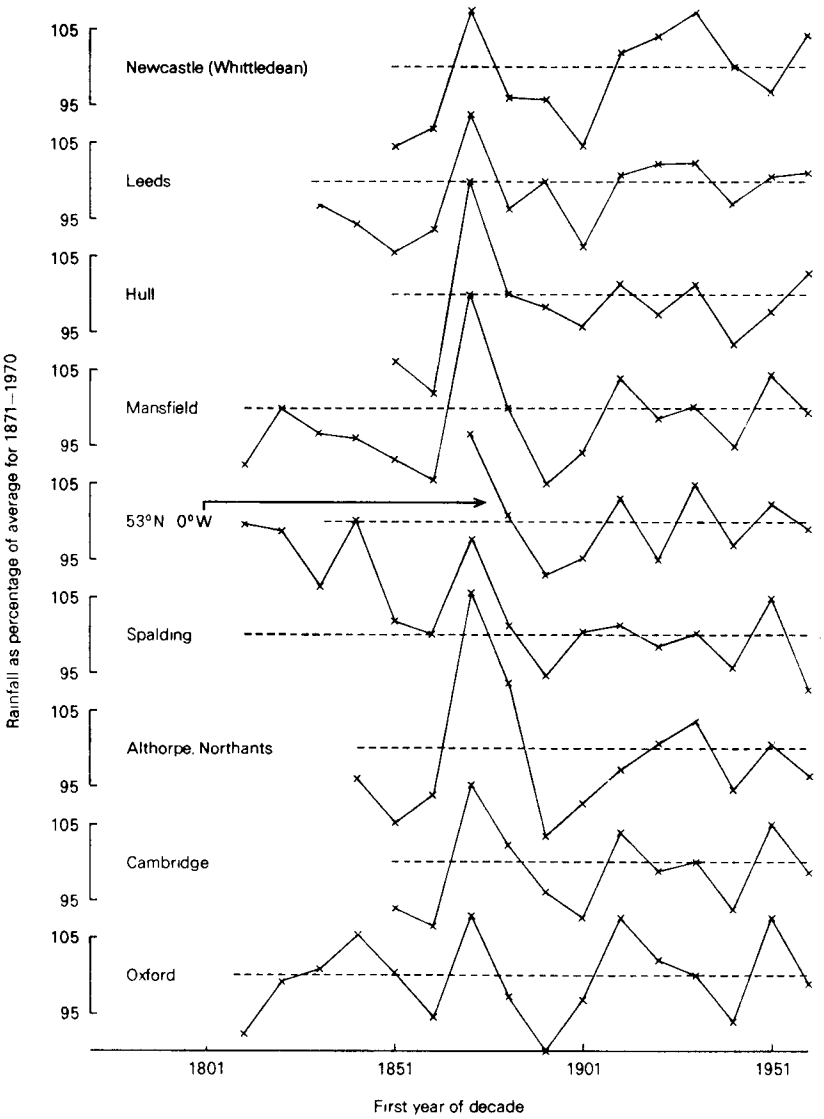

Figure 2. Decadal means of annual rainfall for stations in eastern England.

derived from maps of percentage of average rainfall which were published by the Royal Meteorological Society (1926) for the years 1868–1923, and by the Meteorological Office in *British Rainfall* thereafter. From 1871 onwards the time series for Mansfield, Spalding, and 53°N 0°W are in very close agreement. Before 1870, however, it is clear that the values for Spalding are too high, and there is evidently a discontinuity in the Spalding record around 1870.

3. Examination of the period around 1870

The period from 1864 to 1879 was examined in more detail by comparing annual rainfalls at Pode Hole with those meaned over five surrounding gauges located at a distance of about 25–30 km. The data were obtained from the '10-year' books held in the Meteorological Office. A considerable decrease in the catch at Pode Hole relative to that at the other gauges is indicated.

The rim of the gauge at Pode Hole was at ground level up to 1871, at 3 inches from 1872 until 1890, and at 1 ft or 15 inches thereafter. The change from 3 inches to 1 ft does not appear to have made much difference to the catch, but it is possible that the change in 1871 did, perhaps because of in-splashing when the rim was at ground level. The catch at Pode Hole expressed in terms of that meaned over the five neighbouring gauges was 111·5 per cent from 1865 to 1871, and 101·2 per cent from 1872 to 1879. This suggests that the gauge at Pode Hole shared a similar exposure to its neighbours from 1872 onwards, but caught 10 per cent more before that date. A correction factor of around 10 per cent is consistent with what might have been deduced from Figure 2, where a reduction of the decadal means at Pode Hole by 10 per cent prior to the 1870s would secure a good agreement with the other records.

4. Examination of the period 1800–70

The record produced by Craddock and Wales-Smith for the period 1800–70 is based mainly on data from South Kyme (Lincs.) from 1800 to 1828, and from Pode Hole thereafter. The South Kyme record extends to 1868, but other data examined were for Witham on the Hill (1821–96) and Boston (1826–72), both within 30 km of Pode Hole, plus more distant stations at Derby (1809–35) and Welbeck Abbey, Notts. (1807–76). The subjective judgement from these observations was that the Pode Hole record was good, but that South Kyme caught too much rain between 1814 and 1816 and too little between 1847 and 1856. The catch at Witham also seemed deficient after 1860.

The Pode Hole record was therefore regarded as homogeneous between 1829 and 1871. South Kyme was used to extend the series back to 1800, but the ratio between the rainfalls at South Kyme and Pode Hole was determined using overlaps for both stations with Witham on the Hill. For Pode Hole the period used was 1829–60, while for South Kyme the ratio with Witham was derived from the periods 1821–46 and 1857–60. The high totals received at South Kyme in the years 1814–16 were further reduced by 27 per cent from comparisons with Welbeck Abbey.

5. Examination of the period 1726–1800

For the period 1726–1800 the series is based mainl yon data from Southwick (Northants.) from 1726 to 1739, and Lyndon (Rutland) from 1737 to 1798.

The nearest check on the Lyndon observations is from the record at Chatsworth, Derbyshire (1761–1813). The ratio between annual totals at the two gauges during the period of overlap was not very steady, but a marked change in the ratio, in the sense of an increase in rainfall at Lyndon, took place around 1770. Thomas Barker wrote to the Royal Society describing the site of his gauge on a wall in 1771. It is possible that after this communication, he moved his gauge on to a lawn, being unaware that

this would affect its catch. If the change is assumed to have taken place around 1771 or 1772, then the change in the ratio Lyndon/Chatsworth between 1761–71 and 1772–1800 indicates a change of 15·7 per cent in the catch at Lyndon.

In order to reduce the Southwick record to that at Lyndon, there are only three years of overlap, with the ratio Lyndon/Southwick = 0·913. At Southwick, Craddock and Wales-Smith assumed an average annual rainfall (R) for a standard site of 23·8 inches. This, combined with an estimated oversheltering of 3 per cent gave an expected R of 23·11 inches. At Lyndon an estimated R for a standard site of 24·56 inches may be combined with an over-exposure of 15·7 per cent to give an expected R of 21·24 inches. The ratio of the expected R (Lyndon/Southwick) is 0·919, almost identical to the ratio of the catches that was actually observed. This finding supports the use of the overlapping ratio to reduce the observations at Southwick to those at Lyndon, and the assumptions leading to the estimated over-exposure of 15·7 per cent in the gauge at Lyndon.

The reduction of observations from Lyndon to South Kyme cannot be made with any degree of confidence, but overlaps with Chatsworth of 1772–1800 for Lyndon and 1800–13 for South Kyme suggest a ratio of unity between rainfall at Lyndon and South Kyme.

6. Conclusions

The suggested factors for obtaining a revised rainfall series representative of Spalding are summarized in Table I. They are all uncertain, and by analysing the data in different ways, different results could have been obtained. Nevertheless, the factors presented in Table I are probably just as good as any others, and they do result in a homogeneous series which agrees well with other long-period records. This is illustrated in Figure 1 where the original and suggested series for Spalding are compared with those for England and Wales, Kew, and Hoofddorp. Between the 1770s and the 1860s the old and new series for Spalding are practically parallel, the major differences being the step changes introduced in 1871 and 1771. The first of these is well founded, but the second is open to conjecture. The similarity with the other records available in the eighteenth century implies, however, that the present suggestions are unlikely to be substantially in error. Both authors of the original series for Spalding have agreed to the revisions suggested above.

Table I. *Homogeneous rainfall series for Spalding*

Period	Station	Multiplying factor	
		New	Old
1726–39	Southwick	1·019	1·024
1740–71	Lyndon	1·117	1·040
1772–98	Lyndon	0·965	1·040
1799	West Bridgford	1	1
1800–13	South Kyme	0·965	1·030
1814–16	South Kyme	0·705	1·030
1817–25	South Kyme	0·965	1·030
1826	Witham on the Hill	1	1·011
1827–28	South Kyme	0·965	1·030
1829–71	Pode Hole	0·908	1
1872–	Pode Hole	1	1

Note. The multiplying factors in the column headed 'New' are those which must be applied to the readings from the various stations in order to produce the revised unified series for Spalding which is now proposed; the factors in the right-hand column are those which were used for this purpose by Craddock and Wales-Smith (1977).

Acknowledgements

Thanks are due to Messrs B. G. Wales-Smith and J. M. Craddock for constructive discussions during the course of this revision.

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Supplementary note on 'The northerly gales of 11–12 January 1978' (*Meteorological Magazine*, **108**, 1979, 135–146)

Estimates of wind above the boundary layer

Mr C. L. Hawson of the Special Investigations Branch of the Meteorological Office has given me details of wind speeds recorded at the IBA television mast at Belmont, Lincs. (53°20'N, 00°08'W) on 11–12 January 1978. The anemometer, the property of the Central Electricity Research Laboratories, is mounted on top of the mast at 1275 ft above ground and 1686 ft above mean sea level, and the speeds recorded should be close to the wind speeds in the free air above the boundary layer. No regular instrument checks are carried out, but a number of indirect comparisons have not revealed any consistent error. Winds are measured over 3-minute intervals, and averaging 20 readings provides an hourly mean. The maximum hourly mean speed recorded on 11 January was 65 knots (1400–1500 GMT) and the maximum 3-minute wind speed was 70 knots (1500–1600 GMT).

A trajectory constructed for the air which at 1500 GMT was over Belmont showed no curvature and a geostrophic wind of 74 knots, only a little greater than the Belmont 3-minute wind speed. In some other areas (e.g. north-west of London in the evening) the geostrophic wind was estimated as 90–100 knots, with trajectory either straight or perhaps with slight anticyclonic curvature, implying a wind speed in the free air of about 100 knots. However, these estimates of geostrophic wind are based on synoptic-chart measurements over distances of 30–60 n mile normal to the isobars, and this averaging distance may not be sufficient to exclude appreciable errors. Moreover a larger uncertainty arises in estimating the trajectory and hence its curvature. Broad-scale features of the sea-level pressure charts suggest an overriding tendency to cyclonic curvature, even though in an area 130 n mile square the isobars were straight and unchanging in direction over several hours. In addition, the curvature 'correction' is proportionately much larger for very strong winds than for moderate speeds.

After consideration of these uncertainties there seems little doubt that the hourly mean wind speed in the free air reached 75–80 knots in some places. It may well be that, in certain areas and for limited periods, higher speeds were reached, but of this we have no direct evidence.

The maximum wind aloft is of interest here primarily in its possible relationship to ground-level gust speeds. The Belmont data at 1275 ft may be compared with the maximum gusts recorded at five anemograph stations all within 20 n mile.

Time GMT	13	14	15	16	17	18	19	20	
Belmont 3 min (max.) (knots)	64	69	70	68	67	65	61		
Belmont 60 min mean (knots)	57	65	64	64	64	62	57		
Max gust (knots)									*Time*
Scampton	.	.	.	52	.		.		(1639)
Waddington	.		.	57	.	.	.		(1645)
Cranwell	.	.		.	**61**	.	.		(1739)
Coningsby	.	.	.	.	.	55	.		(1821)
Binbrook	.	.	.	.	.	.	57		(1921)

Mr Hawson also points out that an isallobaric wind theory ascribed to Ertel, and discussed in Panofsky's 'Introduction to dynamic meteorology'*, would on this occasion have produced a vector opposed to the geostrophic wind. This would imply a true wind appreciably less than the geostrophic or gradient wind, in contrast to the theory of Brunt and Douglas which, if tenable, would imply winds of up to 125 knots. However, Panofsky states that observational evidence is inconclusive regarding the relative merits of the two solutions. Although in some circumstances one or the other isallobaric wind construction may seem to apply, neither can be relied on even in so well-marked a case as that of 11–12 January 1978.

E. G. E. King

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* Panofsky, H. [A.]. Introduction to dynamic meteorology. Pennsylvania State University, 1956.

Meteorological Office Scientific Paper No. 38 (The Psychrometer Coefficient of the Wet-bulb Thermometers used in the Meteorological Office Large Thermometer Screen, by C. K. Folland, B.Sc. London, HMSO, 1977)—notification of misprints.

A number of mostly minor misprints have been noted by the author and his colleagues in the above-mentioned Scientific Paper as printed; these represent errors only in the paper as published and not in the work, calculations or conclusions. The four which may be significantly misleading are as follows:

(1). The equations for $(h_c)_{cyl}$ and $(h_c)_{sph}$ near the bottom of p. 22 and at the top of p. 23 respectively should read

$$(h_c)_{cyl} = 74\left(\frac{V}{r}\right)^{\frac{1}{2}} \text{ W m}^{-2} \text{ K}^{-1}$$

and

$$(h_c)_{sph} = \frac{12}{R} + 54\left(\frac{V}{R}\right)^{\frac{1}{2}} \text{ W m}^{-2}\text{ K}^{-1}.$$

The parent equation on p. 22 is correct.

(2). On p. 27, line 3, 'Figure 6' should read 'Figure 16'.

(3). The numerical values for k'_2 and k'' given half-way down p. 31 should be transposed, i.e.

$k'_2 = 10{\cdot}9 \text{ W m}^{-1}\text{ K}^{-1}$
$k'' = 18{\cdot}4 \text{ W m}^{-1}\text{ K}^{-1}$.

(4). On p. 35, in the caption to Figure 21, '58 mm' should read '68 mm'.

Additional errors of less importance are:

(5). On p. 3, Table I, third column, '1·10' should read '1·00'.

(6). On p. 6, Figure 2, the letters 'A' and 'B' should be inserted to identify (I) the second from top curve and (II) the bottom curve respectively.

(7). On p. 9, fourth line from bottom, after 'rate' insert 'of change with temperature'.

(8). On p. 21, line after equation (13), 'L' should be added in front of $h_v\overline{\beta_w}$.

(9). On p. 24, 6 lines from bottom, 'Figure 3' should be 'Figure 6'.

(10). On p. 29, two-thirds of the way down the page, the text should read 'h_c and h_r are evaluated for r_d or r as appropriate (a single prime represents the upper stem lower section and a double prime the upper stem upper section).'

(11). On p. 30, equation (20) should read

$$\left(\frac{dQ}{dt}\right)_{x=0} = kB\left(\frac{d\theta}{dx}\right)_{x=0} = \frac{kBm\,(T_w'' - T_w')}{\sinh mL}.$$

Notes and news

Meteorological Research Committee and Advisory Committee on Meteorology for Scotland

The recent White Paper entitled 'Report on Non-Departmental Public Bodies (Cmnd. 7797, HMSO, January 1980) states that 'the Meteorological Committee will absorb the activities of the Advisory Committee for Meteorology in Scotland, and the Meteorological Research Committee; savings are estimated at £0.003 m'.

Obituary

We regret to record the death on 19 December 1979 of Mr W. F. McKnight, Higher Scientific Officer. William Fairlie McKnight joined the Office as an Assistant in December 1951 and gained promotion to the forecasting grade of Assistant Experimental Officer in 1957. He served at a variety of outstations, both at home and overseas, in his early years in the Office before being posted in 1967 to Glasgow Weather Centre where he was still serving at the time of his death. He was noted for his keen interest in sports and social activities. In his younger days he played Rugby for Kilmarnock in the 1st XV and cricket in the 1st XI, and he was later made honorary life president of Kilmarnock Cricket Club.

We regret to record the death on 25 December 1979 of Mr R. Mills, Scientific Officer. Richard Mills joined the Office as an Assistant in June 1947 after REME service during the war and was promoted to Senior Scientific Assistant in 1964. He served at many outstations at home and overseas in his early career, and also worked for a couple of years in the Communications Section (M.O.5a) at Dunstable and Bracknell. Since 1967 he had been Officer-in-charge of the office at Blackpool Airport. He was a keen and expert gardener and a student of plant-raising and cultivation methods; some of his colleagues may remember his successful efforts in this line while he was stationed in Egypt.

We regret to record the death on 15 January 1980 of Mr J. H. McCabe, Scientific Officer. John Hunter McCabe joined the Office as Scientific Assistant in 1947 and was promoted to Senior Scientific Assistant in 1968. The first 20 years of his service were spent at Leuchars and Lerwick Observatory. He was posted to ATCC Preston in 1967, and was then transferred to Manchester Airport in 1978 when the Preston office closed. He was a keen golfer, and was a founder member of the Barton Hall Golf Society and a member of the Preston Golf Club.

Correction

Meteorological Magazine, **109**, 1980, 74. The first reference on this page should read

Foot, J. S. 1972 Snow accretion on overhead powerlines. *London Weather Centre Memorandum* No. 23.

This memorandum is not unpublished, as previously stated. It can be obtained for £1.50, plus postage, from

The Principal Meteorological Officer,
London Weather Centre,
284–286 High Holborn,
London WC1V 7HX

or

The Director-General,
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Berkshire RG12 2SZ.

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NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ, and marked 'For Meteorological Magazine'.

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